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UNIVERSITY of NOTRE DAME

NASA/USRA UNIVERSITY ADVANCED DESIGN PROGRAM 1990-1991

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FINAL DESIGN PROPOSAL

GAMMA GROUP - THE PALE HORSE

A Proposal in Response to a Commercial Air Transportation Study

May 1991

Department of Aerospace and Mechanical Engineering
University of Notre Dame
Notre Dame, IN 46556

(NASA-CR-190019) GAMMA GROUP-THE PALE HORSE: A PROPOSAL IN RESPONSE TO A COMMERCIAL AIR TRANSPORTATION STUDY ORT STUDY Final Design Proposal (Notre Dame Univ.) 80 p

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THE PALE HORSE

PROPOSEL FOR COMMERCIAL PASSENGER RPV FOR USE IN AEROWORLD

DESIGNED EXCLUSIVELY BY GROUP GAMMA

GRIM REAPER AVIONICS
Division of Acme Inc

DESIGN GROUP MEMBERS:

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Executive Summary

The Pale Horse, designed by Grim Reaper Avionics, is a conventional RPV which will operate in Aeroworld as a 30 passenger aircraft. The major design concerns were cost, range, and passenger comfort. Economic analysis concludes that approximately 150 aircraft flying 8 missions of an average distance of 2,150 feet per mission, will comfortably accommodate the needs of Aeroworld. A rate of $12 per 50 feet plus a $50 flat rate will be profitable to the airlines and will be competitive with the other modes of transportation for the Ping-Pong people of Aeroworld.

The SD7062 is the airfoil for the Pale Horse. The rectangular wing, with an 8 foot span and 10.5 inch chord, will be mounted high on the fuselage with 10 degrees of dihedral for increased roll stability. The wing will be hinged 1.5 feet from each wing tip to utilize the 5 foot as well as 7 foot gates at Aeroworld airports. The hinge enables the wing tips to be folded upward during loading and unloading in the airport gates. To keep the wing straight during flight, tape will be placed along the lower edge opposite the hinge.

Structurally, the Pale Horse will consist mainly of balsa wood and glue, with Monokote making up the skin of the aircraft. The fuselage will consist of a balsa wood keel which has been designed to withstand the majority of the stress due to aerodynamic forces. Ribs attached to the keel will form a rounded fuselage that will reduce drag effects.

Internally, all servo motors, batteries, and electronics will be placed near the front of the aircraft for stability considerations. Passengers will be seated in two rows of 15, with a center aisle for safety and comfort. Aft of the passenger cabin will be space for a restroom as well as a galley for guest comfort. Beneath the passenger area will be a luggage storage hold which will also house the control rods to the rudder and elevator.

An Astro-15 electric motor will be used to power the Pale Horse. Connected to the motor will be a Tornado 10-6 propeller, and driving the motor will be thirteen 1.2 volt/1.2 amphr batteries connected in series. This propulsion system enables the aircraft to be maneuverable with a desirable rate of climb and a take-off distance less than 38 feet.

The empennage is sized to provide longitudinal and lateral stability during maneuvers. Control surfaces consist of elevators and a rudder. Roll stability in turns will be maintained by 10 degrees of dihedral in the wing as well as a dorsal fin mounted to the fuselage. With a center of gravity located aft of the aerodynamic center of the wing, the static margin will be approximately 15%, producing desirable handling qualities.

The flight range for one battery pack is over 20,000 feet, therefore a fully charged Pale Horse can fly its 8 daily flights including taxi and delay times on a single charge. This reduces Aeroworld gate times, thus allowing for quicker turnovers between flights. In addition, this reduces maintenance costs which allow the airlines to pass the savings on to the passengers.

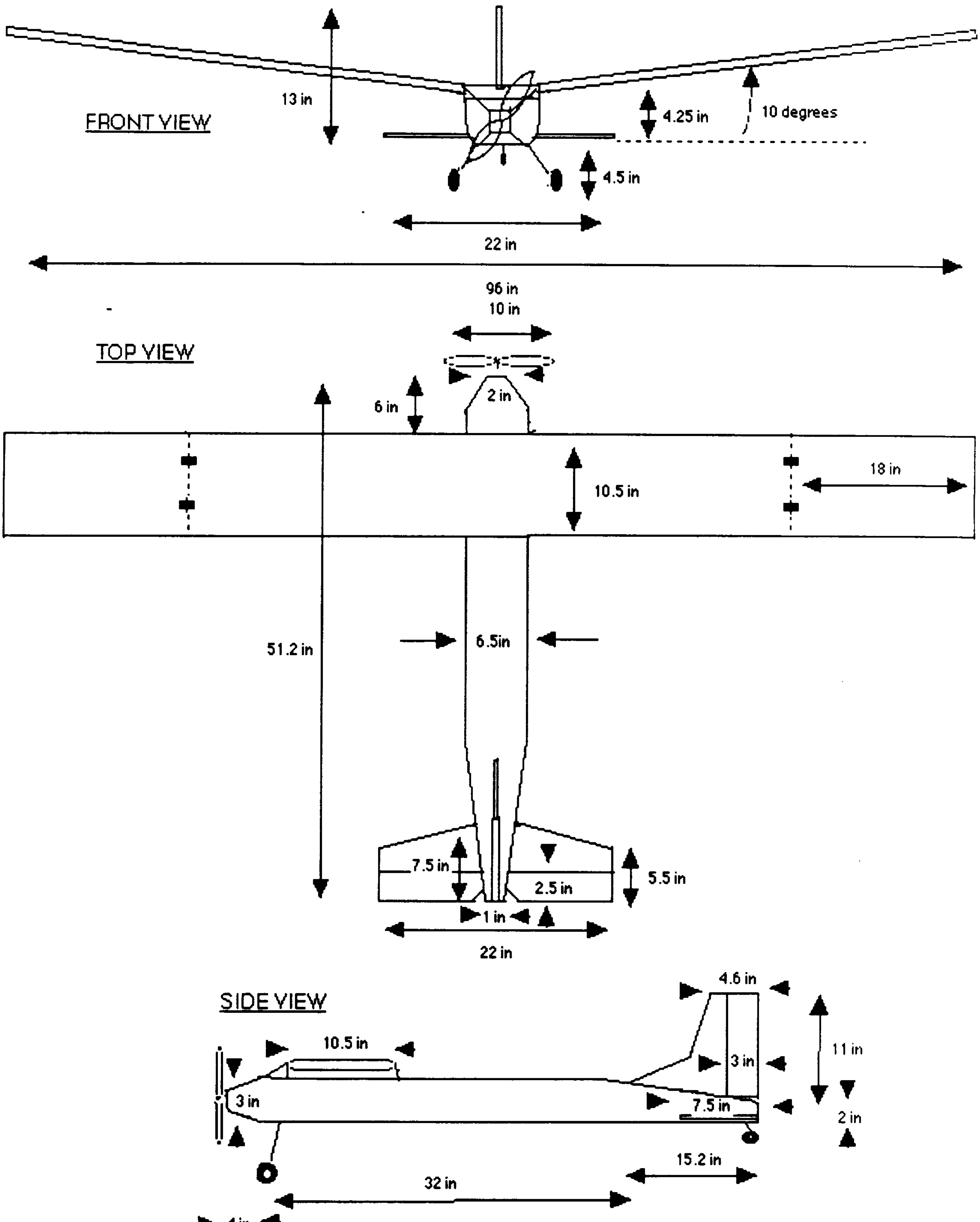
Concerns in the design include the hinge design and structural failure resulting from the inexperience of the manufacturers. Prototype studies give confident results for the

effectiveness of the hinge. Throughout the design, large factors of safety have been included to reduce the apprehension for the latter concern.

The Pale Horse is a safe, comfortable, and profitable aircraft, providing rapid and cost efficient travel throughout Aeroworld. Come fly the deadly skies! - Grim Reaper Avionics.

PALE HORSE

3-VIEW



SPECIFICATIONS SUMMARY

RPV DESIGN CHARACTERISTICS:

Weight = 4.98 lbs.
Wing Span = 8.0 ft.
Aspect Ratio = 9.14
Dihedral = 10 degrees
Cl max = 1.3
Cl cruise = .7
Engine = Astro 15
Propeller Efficiency = .76
Fuselage Width = 6.5 in.
Max. Load Factor = 1.5
Vertical Tail Area = .46 ft^2
Battery Pack Voltage = 15.6 V
Airfoil = SD7062

Wing Chord = 10.5 in.
Wing Area = 7.0 ft^2
e =.78
Wing Mount Angle =4.7 degrees
Cl takeoff =.7
Cdo = .048
Propeller = Tornado10-6
Fuselage Length = 51.2 in.
Finess Ratio = 7.87
# of Passengers = 30+3 crew
Horizontal Tail Area =.97 ft^2
Battery Pack Capacity = 1200 mah
Horiz. & Vert. Stab. Airfoil = Flat Plate

RPV PERFORMANCE DATA

(Environment - Standard Sea Level Conditions)

Stall Speed = 23.3 ft/s
Cruise Speed = 30 ft/s
Cruise Altitude = 20 ft.
Landing Distance = 57 ft.
Endurance @ 30 ft/s = 646.8 s

Max. Speed = 35 ft/s
Cruise Reynolds Number = 153500
Takeoff Distance = 33 ft.
Range = 20000 ft.
Rate of Climb max = 9.0 ft/s

Mission

The primary consideration for the design of the Pale Horse was its status as a commercial transport for Aeroworld. The need to service the traffic of the world presented not only technical design decisions, but also required consideration of routing possibilities, comfort considerations, and economics analyses. The routing was therefore the start of the design process for Grim Reaper Avionics.

The geography of Aeroworld and the routing scheme used for the design objectives of the Pale Horse are both shown in Figure 1.1. A total of thirty two routes are employed, all with a required flight and loiter distance of 5,520 feet or less. Routing for longer flights, such as A to O, was accomplished with the fewest stopovers. For example, A to O was routed A-C-D-E-O, and A to K was routed A-B-G-K. Using this routing pattern and the passenger load table included in the request for proposals, (Table 1.1), a count of the passenger load on each route, per day, was calculated. (Table 1.2). At maximum rate of operation, total of 31,720 passengers would travel in Aeroworld.

Translating the routing scheme into design objectives was relatively easy. Implicit in the routing scheme is the assumption that the Pale Horse can take off and land in under 37.5 feet, to enter city O. Operability in all of the Aeroworld's airports has become an objective, while takeoff in 60 feet is the design requirement set by the group. The loss of service to O decreases the total passenger load by 660 per day. Because route A to C has more than 600 passengers using it each day, service to city C is important in keeping the northern routes, such as F to J, clear. The gates open at each airport also came into the design consideration. To service all the cities, a maximum in-gate wingspan of 5 feet was needed. The wingspan became a parameter in the design for the Pale Horse. To increase the aspect ratio and provide more lifting surface, a longer wing was desired. To remain with the goal of servicing the airports and accommodate all gates, a hinged wing was considered.

The comfort of the passengers was next on the list of considerations. To allow for comfort, each passenger was allowed a 2 inch by 2 inch by 2 inch section of the passenger cabin. To keep the length of the fuselage manageable, only 30 inches were allowed for the passenger cabin. With fifteen rows of two, and an aisle down the center of the plane, the minimum fuselage size was determined for thirty passengers. This also helped in determining the number of planes needed for an airline fleet. For the maximum passenger load of 31,720, an airline would require 1065 flights, with 148 Pale Horses flying eight missions per day. A pilot and copilot were added to in the passenger number. Our idea of a self serve salad bar failed its marketability test, so a stewardess was added onto the crew. Space was allowed for baggage , a galley, and a restroom. Another topic related to comfort was speed of the aircraft. To be competitive with rail or boat transportation, the Pale Horse would require some kind of advantage over these alternatives. Flying near the speed of sound would give that advantage. People are willing to pay more to arrive at their destination quicker.

Although economics is addressed in a later section, some price restrictions were placed on the design before any analysis was made. First, the Pale Horse could not cost more than $250,000 to produce. Next, to be competitive with other modes of transportation, fares were set at a maximum of $12 per 50 feet, plus a $50 flat rate. Also, an average Pale Horse would use less than 1200 milliamp-hours in one day; at a maximum fuel cost of $120 per mah, this is a fuel cost of no more than $144,000 per plane per day. Finally, one four minute maintenance period would be given to each plane, each day. This entails changing batteries for the technology demonstrator. At $500 per man minute, this gives a maintenance cost of $2000 per plane per day. This turned out to be a large design requirement, since this means that the average Pale Horse would need to fly eight missions on a single battery charge.

The remaining mission objectives deal with the technical matter of making the Pale Horse fly. A weight of no more than 5 pounds was desired. A thrust of 2 pounds was estimated to take off in the targeted distance, with a propeller that was most efficient at a velocity of 30 ft/s. A horizontal stabilizer and vertical tail would be used for pitch and yaw stability, while a high mounted wing with dihedral would prevent rolling. The center of gravity would be placed so that the horizontal tail would not be a major lifting surface during cruise. For control, a rudder and elevators operated by servos would be used. No roll control would be used. The following list is a summary of the design requirements and objectives:

*External Configuration

- -In gate wingspan of 5ft.
- -Rounded fuselage and empennage - reduce drag.
- -Horizontal tail not a lifting surface.
- -Conventional landing gear.

*Internal Configuration

- -Passenger cabin 6 in wide, 30 in. long, 2 in. high.
- -Cockpit for a crew of 2 pilots.
- -Galley
- -Restroom
- -Baggage storage - approximately 1 square in. per passenger.
- -Easy to load passengers.

*Propulsion

- -1.5 to 2.0 lb of static thrust.
- -Easy access to batteries.
- -Most efficient propellor between 26 and 34 ft/s.
- -Vented propulsion space to prevent overheating.
- -Lightweight propulsion system.

*Structures

- -Max weight of 5lbs.
- -Construct of common/inexpensive materials.
- -Lightweight hinge for wing tips.

*Stability

- -Vertical and horizontal tail
- -High wing with dihedral

*Control

-Horizontal tail	-out of wake of wing.
	-non lifting surface.
	-stabilizing moment about CG.
	-low drag.
	-controlled by servo motor.
-Vertical tail	-roll control, enough to counter yaw.
	-rudder large enough to turn RPV w/o ailerons.
	-controlled by servo motor.
	-CG placed so tail not a lifting surface.

*Performance

- -Take off length of 60 ft or less.
- -Cruise velocity not to exceed 35 ft./s, target 30 ft/s
- -Minimum range of 5600 ft.
- -Turn radius no greater than 60 ft

*Cost / Manufacturing

- -Cost of materials per plane not to exceed $600.00(Real World)
- -Not to exceed 150 man-hours to build.
- -Maintenance costs shall not exceed $2,000 per day per plane.
- -Daily fuel costs shall not exceed $117,000 per plane.
- -fare shall not exceed $12 for every 50 ft. + $50 flat rate.

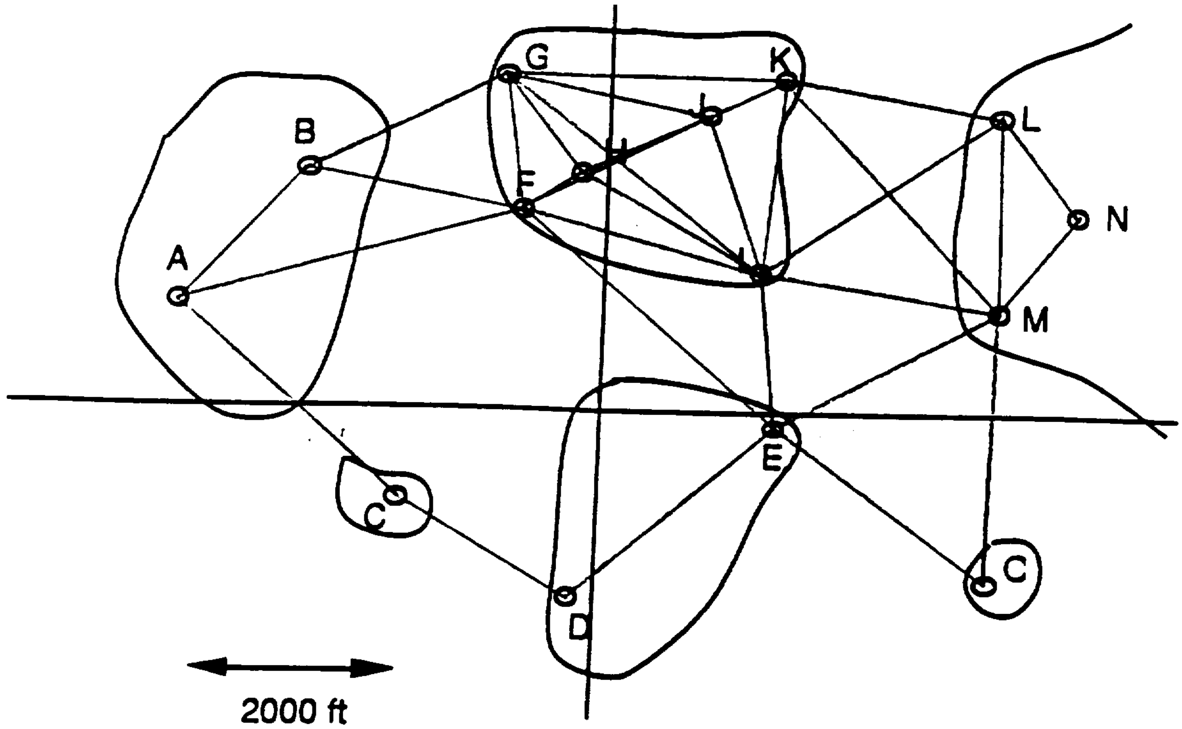


FIGURE 1: "AERO-WORLD" GEOGRAPHY

CITY	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
A	0	500	200	20	20	200	350	40	100	300	350	80	60	80	20
B	500	0	100	20	20	350	400	60	150	400	400	400	100	200	20
C	200	100	0	30	20	120	90	30	30	30	50	300	30	20	20
D	20	20	30	0	150	60	40	30	90	60	80	30	20	20	20
E	20	20	20	150	0	100	30	20	200	100	200	60	30	30	20
F	200	350	120	60	100	0	350	60	250	400	500	250	200	250	20
G	350	400	90	40	30	350	0	300	300	300	250	200	150	120	20
H	40	60	30	30	20	60	300	0	200	250	250	100	100	200	20
I	100	150	30	90	200	250	300	200	0	350	450	250	200	200	20
J	300	400	30	60	100	400	300	250	350	0	500	300	250	300	20
K	350	400	60	80	200	500	250	250	450	500	0	400	450	500	20
L	80	400	300	30	60	250	200	100	250	300	400	0	350	400	20
M	60	100	30	20	30	200	150	100	200	250	450	350	0	350	20
N	80	200	20	20	30	250	120	200	200	300	500	400	350	0	20
O	20	20	20	20	20	20	20	20	20	20	20	20	20	20	0

TABLE 1. DAILY PASSENGER LOAD

Table 2 routes and flights

Route	Distance	Range Required forward	backward	Estimated Traffic (2 way)	Flights Required	Planes Required	Passenger miles
A-B	1700	3400	3400	1650	55	7	2805000
A-C	3120	5180	4820	610	21	3	1903200
A-F	3500	4220	5200	1100	37	5	3850000
B-F	2240	2960	3940	980	33	5	2195200
B-G	2240	3520	3940	2160	72	9	4838400
C-D	2060	4120	4120	660	22	3	1359600
D-E	2700	4320	4760	1190	40	5	3213000
E-F	3400	4120	5020	300	10	2	1020000
E-I	1620	3240	3240	890	30	4	1441800
E-M	2500	3780	4080	540	18	3	1350000
E-O	2720	5440	4340	120	4	1	326400
F-G	1420	2700	2160	420	14	2	596400
F-H	720	1440	1440	210	7	1	151200
F-I	2480	4100	3200	1120	38	5	2777600
F-J	2060	2960	2780	2250	75	10	4635000
G-H	1280	2000	2560	300	10	2	384000
G-I	3280	4900	4560	300	10	2	984000
G-J	2560	3460	3840	300	10	2	768000
G-K	2800	3700	4080	2410	81	11	6748000
H-I	2060	3680	2780	650	22	3	1339000
H-J	1340	2240	2060	600	20	3	804000
I-J	1700	2600	3320	560	19	3	952000
I-K	2020	2920	3640	780	26	4	1575600
I-L	2880	4160	4500	700	24	3	2016000
I-M	2440	3640	4060	1010	34	5	2464400
J-K	900	1800	1800	2550	85	11	2295000
K-L	2240	3520	3140	2200	74	10	4928000
K-M	3260	4540	4160	1530	51	7	4987800
L-M	2000	3280	3280	780	26	4	1560000
L-N	1280	2560	2560	1300	44	6	1664000
M-N	1280	2560	2560	1390	47	6	1779200
M-O	2800	5520	4080	160	6	1	448000

Concept

2.1 Introduction

Each member of Grim Reaper Avionics developed a personal concept to meet the prescribed mission. All were compared with emphasis on the following:

(1) Wing size, placement and design
    gates: 5 foot vs. 7 foot
    low vs. high wing for stability and ground effects
(2) Fuselage shape
    cross section
    side-view shape
    passenger placement-internal configuration
    easy access to mechanical components
(3) Empennage configuration
(4) Overall ease of construction
    structure
    cost

Figures 2.1 through 2.3 are three of the concepts which were integrated into the Pale Horse.

2.2 Concept 1

Figure 2.1 is an individual concept utilizing a five foot wingspan. The wingspan will allow the aircraft to dock at all Aeroworld airports. The fuselage is octangular, tapering on both ends in order to reduce drag. The internal configuration will seat 30 passengers: 15 per side with an aisle down the middle to provide comfort during loading and travel. Landing gear configuration is that of a tail dragger, which would allow the aircraft to be at an angle of attack on the ground and thus produce additional lift at take off. The wing is mounted on top of the fuselage to reduce ground effect and to aid in roll stability. Control surfaces include elevators and a rudder. The rudder will be responsible for turning the aircraft at the low velocities it will be flying at.

2.3 Concept 2

This design possessed a 7 foot wingspan with taper to reduce stress at the fuselage. This wingspan will only be able to dock at some of the Aeroworld airports, but will produce more lift during flight. The wing is mounted on top of the fuselage to produce roll stability and reduce ground effect. The fuselage is circular to reduce drag and tapers to the keel only 32 inches from the front of the airplane. The internal layout will consist of three decks and will hold 32 passengers in the lower two with an upper deck reserved for the control rods. By tapering the fuselage right behind the wing, the drag is greatly reduced and space is conserved. This design also has a rear wheel forming a tail dragger configuration.

2.4 Concept 3

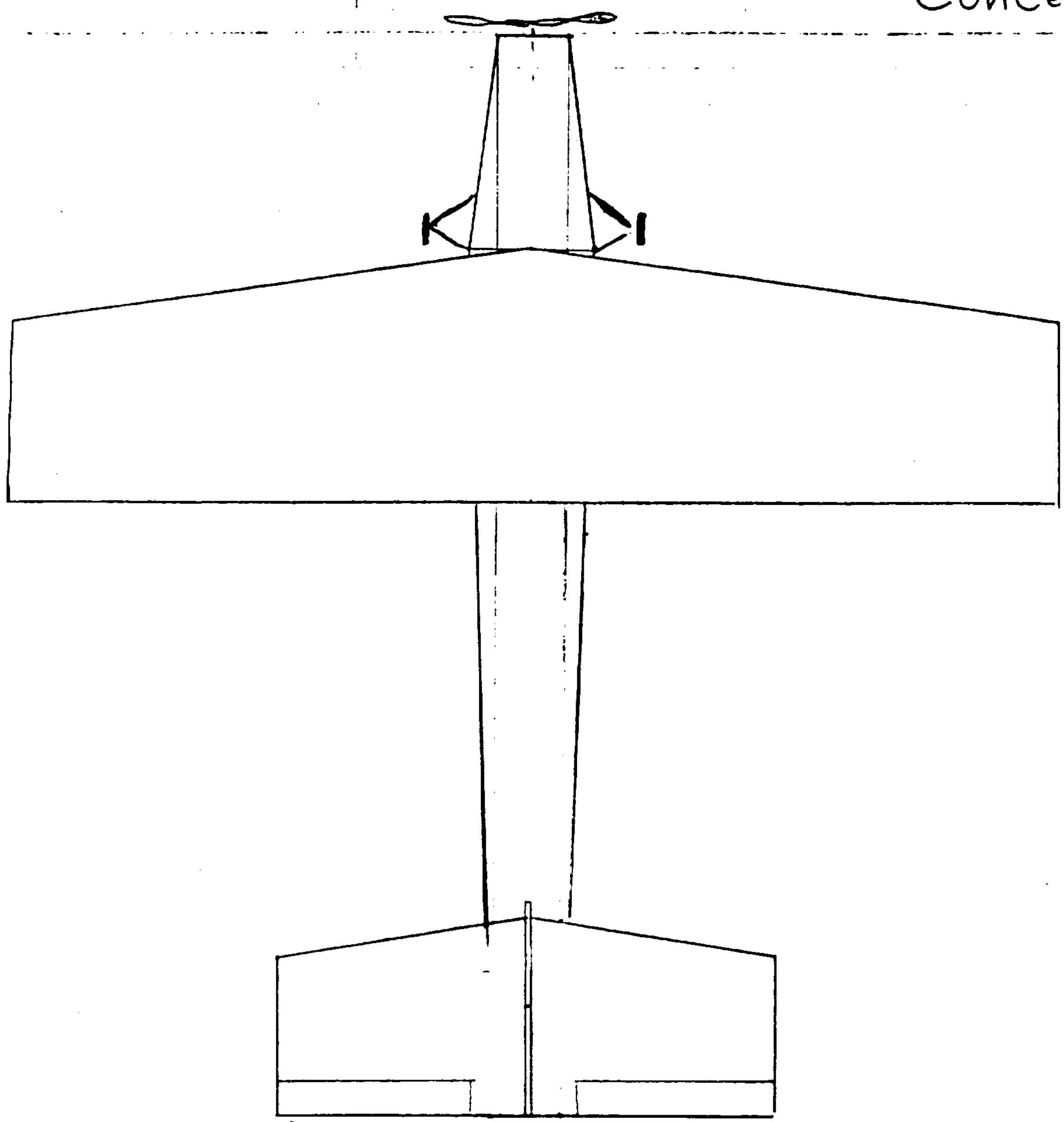
The major feature of this design is the hinged wing. This design allows for the increased lift and the lowered induced drag of a 7.0 ft. wingspan but allows the aircraft to use both the 5.0 ft. and 7.0 ft. gates at the airports in Aeroworld. This design also uses the tapered fuselage which is intended to decrease the drag during flight. The rectangular cross section of the fuselage is intended for the ease of construction and allows for the maximum comfort of the 30 passengers being carried in the cabin that runs the length of the fuselage. The cabin has two rows of passengers with a aisle between them in the cabin area under the wing while the cabin that stretches from slightly aft of the wing to the empennage caries a single row of passengers with a single aisle along one of the cabin walls. Like the previous two, this design uses only elevators and a rudder to control the aircraft during flight. The high wing attachment will aid in roll stability since there are no ailerons. Conventional landing gear is used in order to get a high angle of attack at lift off without any high lift devices incorporated into the wing design.

2.5 The Pale Horse

The Pale Horse embodies the desirable qualities of each of the preliminary concepts. The Executive Summary, which includes a 3 - view and a Specification Sheet, gives a descriptive overview of the concept for the Pale Horse. The remaining portion of this document supports the design of the Pale Horse and shows that the Pale Horse is a safe, fast, and profitable aircraft to operate in Aeroworld.

TOP VIEW SCALE 1in = 10in

Figure 2.1
Concept 1



SIDE VIEW

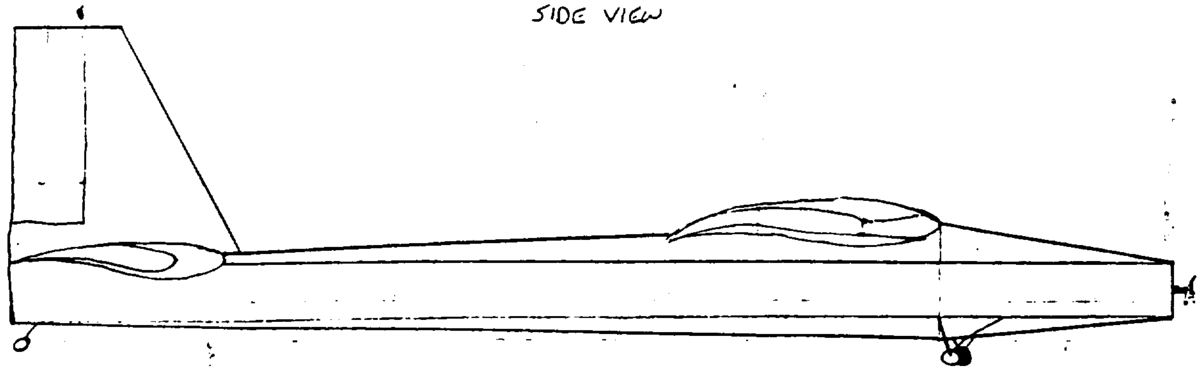
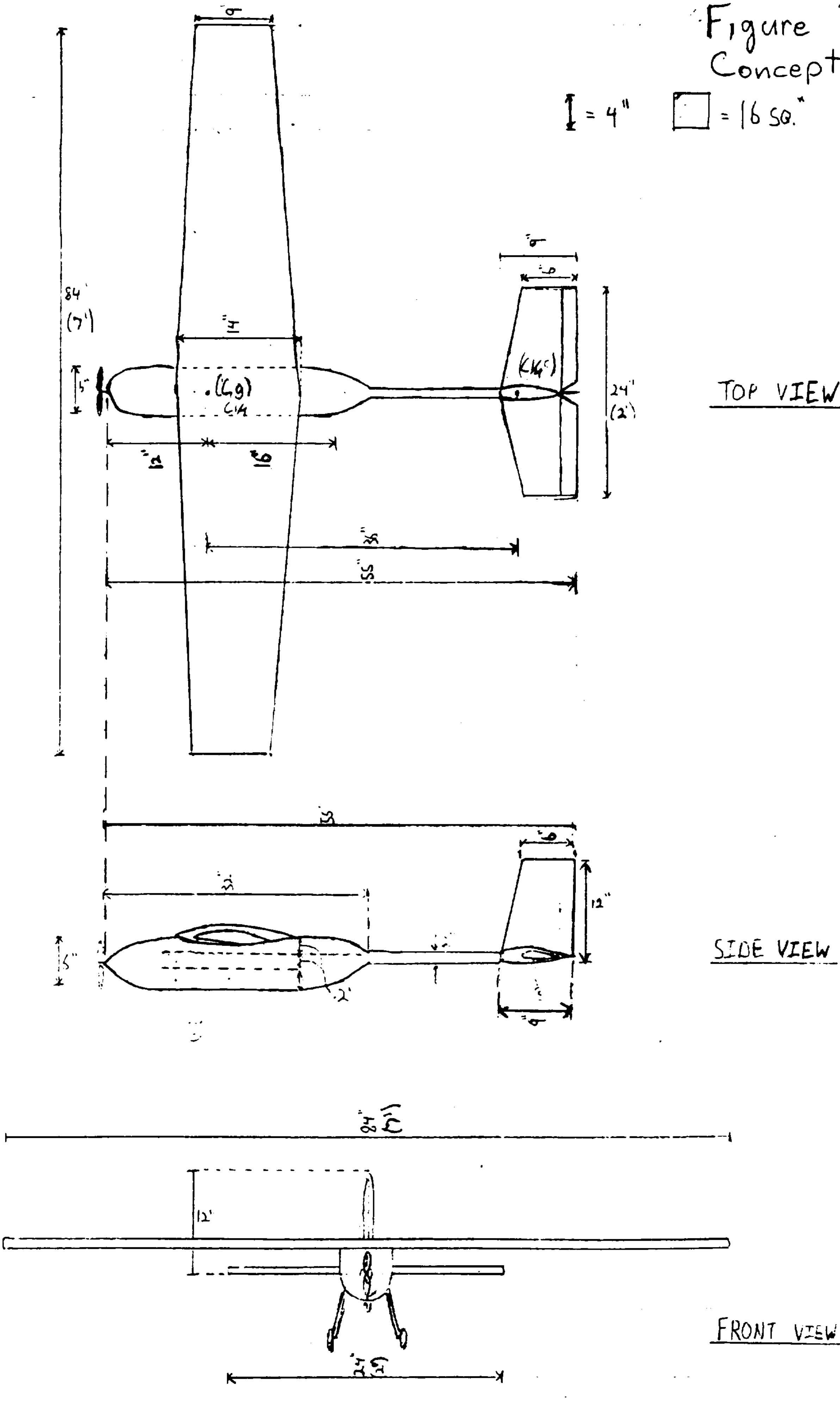
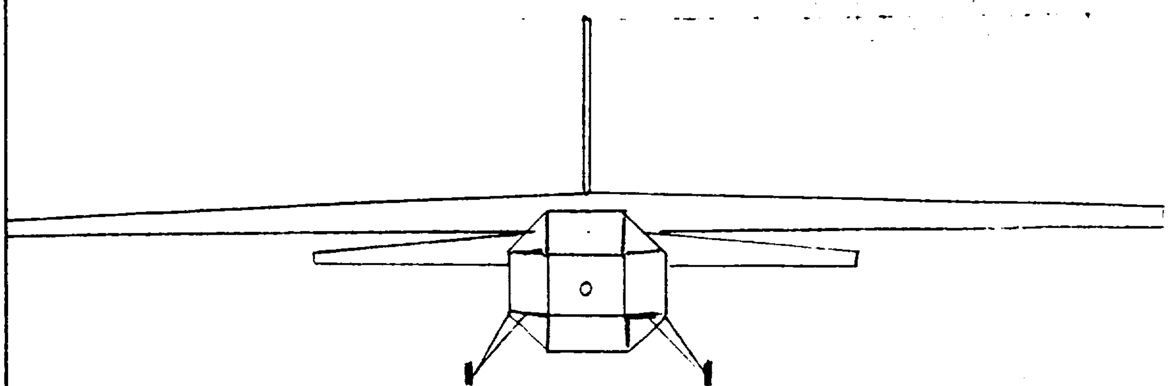


Figure 2.2
Concept 2



FRONT VIEW - ORVAIR 22



WING AIRFOIL - WORTMANN FX-63

MOUNTED AT 4° RELATIVE TO FUSELAGE

$S = 5 ft^2$

$AR = 5$

ROOT CHORD = 14 IN

TR = 0.714

H. TAIL: AIRFOIL - WORTMANN FX-63

MOUNTED AT NO ANGLE RELATIVE TO FUSELAGE

$S = 1.94 ft^2$

$AR = 2.8$

ROOT CHORD = 11 IN

TR = 0.918

V. TAIL: AIRFOIL - FLAT PLATE

$S = 0.75 ft^2$

CONTROL SURFACES: RUDDER $A = 0.278 ft^2$

ELEVATOR 2 @ $A = 0.153 ft^2$

FUSELAGE: $L = 5 ft$

CROSS SECTIONAL AREA: $0.333 ft^2$

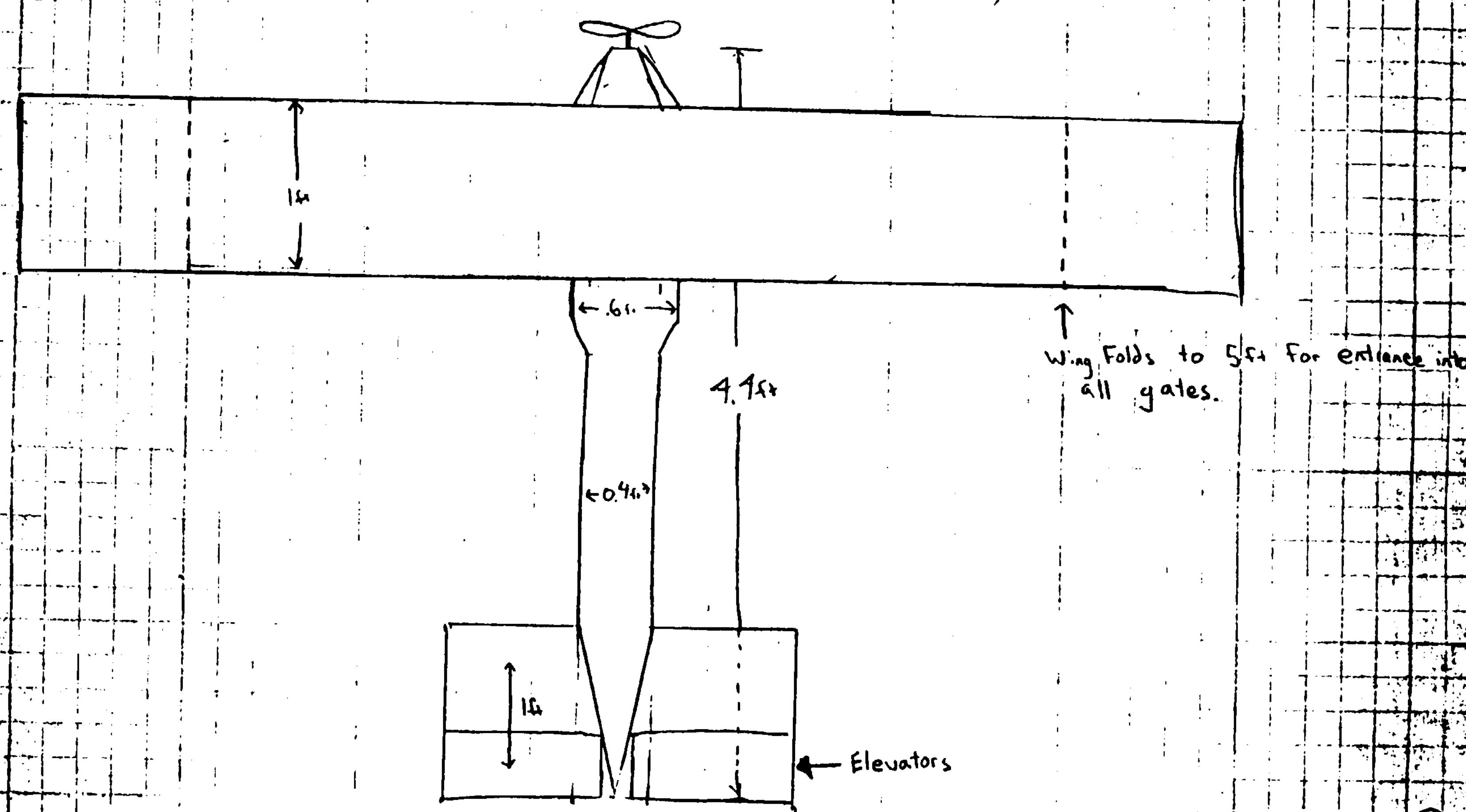
HYDRAULIC DIAMETER $0.632 ft$

L/D_H 7.91

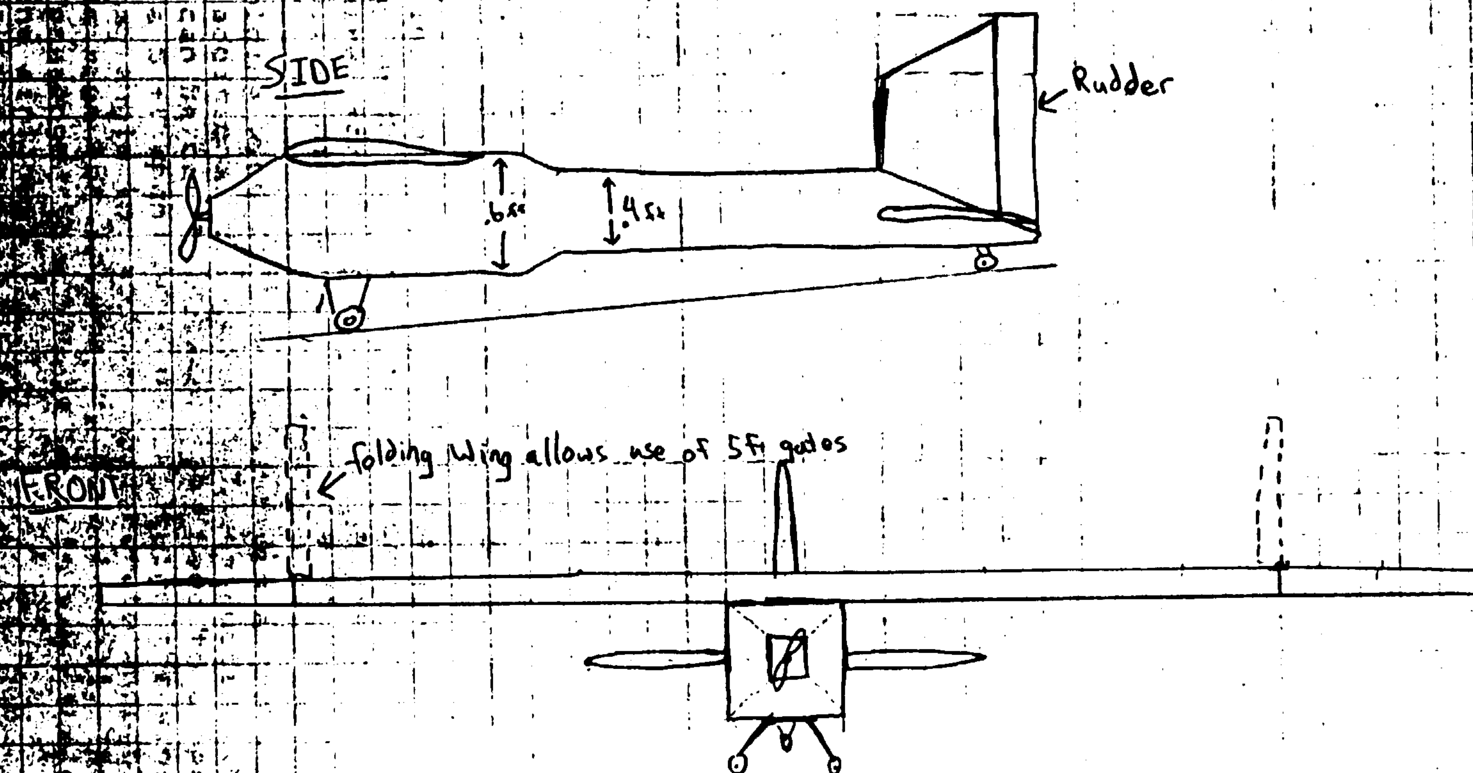
Top

Figure 2.3

Concept 3



1 in = 1 foot



SIDE
Rudder
.6ft
.4ft
FRONT
folding Wing allows use of 5ft gates

Cost and Economics

3.1 Introduction

The bottom line for the airline business is profit. In the following section the projected cost to build the Pale Horse is outlined along with a proposed economic plan for prospective airlines on Aeroworld.

3.2 Projected Costs

The Pale Horse prototype will be manufactured in the Aerolab by a construction team consisting of all of the group members and overseen by the Chief Engineer. The group will use laboratory equipment such as bandsaws, sanders and Exacto knives for sizing the solid balsa and spruce, and hot irons for applying the monokote to the aircraft frame. Manufacture time for the PALE HORSE is targeted between 100 and 150 man-hours. This production time will add between $10,000 and 15,000 to the total production cost, ($100.00 per prototype construction man-hour).

The cost of specific items to produce the Pale Horse can be broken down as follows:

PROPULSION:	
Propeller	$2.00
Engine(Astro 15)	$105.00
Speed Controller	$100.00
Batteries(13)	$30.00
TOTAL	$237.00

CONTROLS:	
Futaba Radio System	$116.00
Micro Servos(2)	$66.00
Control Rods	$4.00
TOTAL	$186.00

STRUCTURE:	
Wood(balsa and spruce)	$45.00
Monokote	$22.00
Hinges/Clamps(17)	$10.00
Landing Gear	$8.00
Glue/Tape	$20.00
TOTAL	$105.00
50 % Error	$53.00
TOTAL	$158.00
TOTAL	$581.00

The actual cost of these materials was determined by pricing them at local Hobby shops.

The ceiling cost for the structural items is $205. The projected spending of $158.00 is well below this cost, even with an error factor included. The factor is included due to the inexperience of Grim Reaper Avionics in manufacturing prototype aircraft. A conservative figure of using 50% more material than needed to build one prototype aircraft should alleviate this inexperience.

In Aeroworld this projected cost is equivalent to $233,000.($400.00 per actual dollar spent on prototype) With the labor costs included, the total cost of the prototype is estimated to be between $243,000 and $248,000. The amount of profit to be made by Grim Reaper Avionics on the PALE HORSE was determined to be 20% of the cost to manufacture the prototype. This increased the total cost of the aircraft to $300,000.

3.3 Proposed Economics

In analyzing the passenger load and distance between cities on Aeroworld, the group proposed that the air carrier purchase 150 planes at a cost of

$45,000,000. This would allow for the 17,500 prospective passengers, traveling round trip, to fly the average distance of 2,150 ft between cities. Only 148 planes would be needed to fly each day at maximum capacity with 2 planes in reserve. Each plane would fly a total of 8 flights per day; this allows for approximately 1200 flights to be flown per day.

The proposed airfare was computed by analyzing the rates of competition travel and by estimating the total operating costs of an average flight. To earn a profit an airfare of $12/50 ft + $50 flat rate was computed. The average flight costs $566.00.

The maintenance expense of the aircraft was estimated to be $2,000 per day per plane.($500.00 per man-minute maintenance) This extremely low cost was due to the range of the PALE HORSE which allows for the batteries to be changed only once per day. The estimated time to change the batteries was estimated to be only four minutes. If maintenance costs exceed $2,000 per day, then the airline will be losing money

The other operating expenses of an average flight besides maintenance expenses of $250.00 are fuel and salary costs. During an average flight, including take-off and taxi, 134 milli-amp hours would be spent totaling $12,037.(fuel costs between $60.00 and $120.00 per milli-amp hour for an average of $90.00) The salaries were estimated by considering the total operating costs of a flight. The group considered 26% of the operating expense to be reasonable for employee salaries. These salaries include those earned by the pilot, flight attendants and sales, baggage handling, ground handling, and administrative personel. This 26% portion of operating costs created an average employee wage pool of $4300.00 per day.

The total expense of an average flight was then estimated to be $16,600.00. The total revenue of an average flight was calculated to be $16,980.00. When considering a full day of travel, with 1200 full flights, the net income per day was $278,000.00 and per year was $101,747,000.00. With only 75% of the population on Aeroworld flying, the number of flights could be cut and the daily net income would be $208,500.00, the yearly $76,310,000.00.

Grim Reaper Avionics proposes that the investment in the planes be amortized over 15 years using a straight line method. This amortization will decrease profits over the 15 year period by $3,000,000 per year.

The Pale Horse compares to the other modes of travel on Aeroworld as follows:(average travel distance)

	Pale Horse	Train	Ship
Fare:	$12/50ft+$50flat	6.25/50ft+$50flat	$8/50ft+65flat
Cost:	$566.00	$318.00	$409.00
Speed:	30 ft/s	9 ft/s	7 ft/s

The speed of the other means of travel were computed using real world average speeds with the speed of sound on Aeroworld being 35 ft/s.

When considering the comfort, speed and safety of the Pale Horse, Grim Reaper Avionics considers it the best means of transportation on Aeroworld.

3.4 Summary

The following table summarizes the projected cost and economics for the Pale Horse.

Cost:

	Manufacture Time:	Aeroworld Cost:
	100 - 150 hours	$10,000 - $15,000
	Materials Cost:	Aeroworld Cost:
	$581.00	$233,000
	TOTAL:	$243,000 - $248,000

Economics: Average Flight:
2,150 feet
Fare - $566.00
Fuel Cost - $12,037.00
Maintenance Cost - $250.00
Total Operating Cost - $16,000.00
Total Revenue - $16,980.00

Overall Flight Plan:
Number of Planes - 150(148 operating per day)
Number of Flights - 1200
Airfare - $12/50ft + $50 flat

Income:
Per Day - $278,000.00
Per Year - $101,747,000.00

Aerodynamics

4.1 Airfoil Selection

One of the most important selections in design for an aircraft is the airfoil. The airfoil must have good performance in the desired flight envelope of the aircraft. In order to reduce cost, however, it must also be simple to construct. For example, the FX63-137 has fantastic performance at low Reynolds number, but is prohibitively hard to construct because of the thin and curved trailing edge. The measures of merit used in the airfoil selection process were:

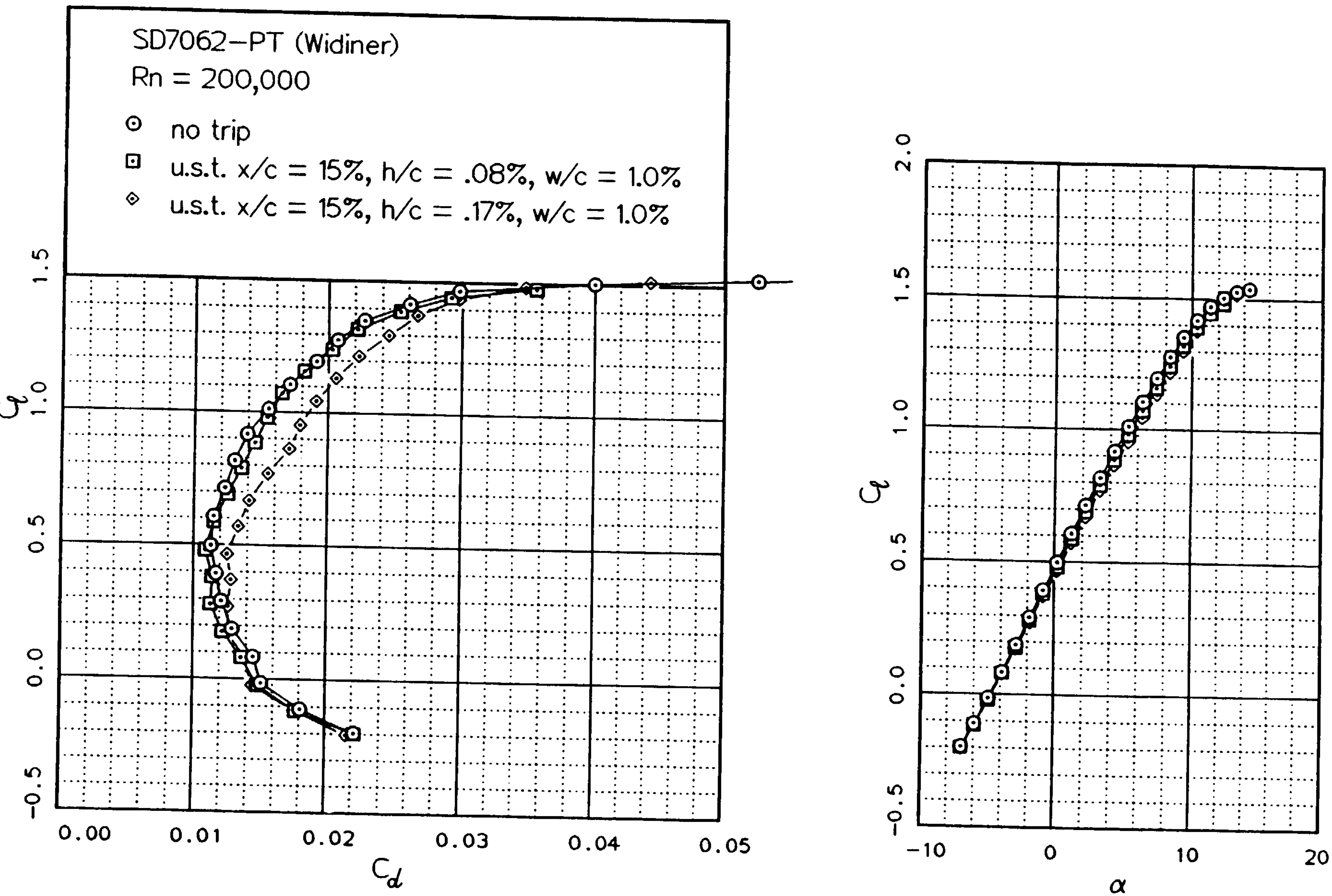
1. High Clmax at low Re
2. Thickness
3. Relatively flat bottom surface
4. Thick trailing edge

The Pale Horse will be flying at a Reynolds number of 175000 at cruise. Therefore, in selecting an airfoil, one of of the key characteristics would be to chose a airfoil that has good characteristics at low Reynolds number flight. Thick airfoils can reduce the stress in the wing section, thereby allowing us to construct a lighter wing. The flat bottom would aid greatly in the cutting of the ribs for the wing. The thick trailing edge would also contribute to ease of construction. With these criteria in mind, several potential airfoils were considered for use in the Pale Horse. The candidates were then narrowed down to two, the Spica and the SD7062.

The Spica is a true flat-bottomed airfoil with a thickness of 11.72% and a camber of 4.74%. At a Reynolds number of 200,000, it has a Clmax of 1.4 and a stall angle of about 15 degrees. The SD7062 is not truly flat-bottomed, but is nearly so, with a 14% thickness and a 4% camber. At a Reynolds number of 200,000, it has a Clmax in excess of 1.5 (Fig 4.1). The experimental data does not show the stall angle precisely, but it would be safe to assume a stall angle of about 15 degrees. In addition, the SD7062 has slightly better drag characteristics. Both airfoils have relatively thick trailing edges.

The SD7062 was selected because of its larger Clmax and thickness. The high Clmax will aid in the take-off, landing, and turning flight of the aircraft, and the thickness will allow for a lighter wing to be built. The bottom surface is slightly curved, but not enough in our judgement to discourage approving the SD7062. It is thicker than the Spica, allowing for a lighter supporting structure in the wing (stress decreases with increasing moment of inertia). For these reasons we chose the SD7062 airfoil for the Pale Horse.

FIGURE 4.1

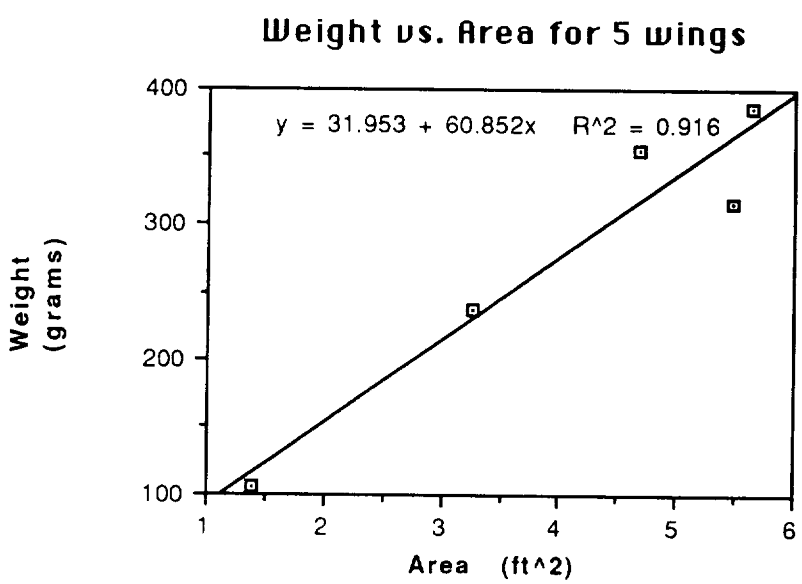


SD7062–PT (Widiner)
Rn = 200,000
no trip
u.s.t. x/c = 15%, h/c = .08%, w/c = 1.0%
u.s.t. x/c = 15%, h/c = .17%, w/c = 1.0%
C_l
C_d
α

4.2 Wing Geometry

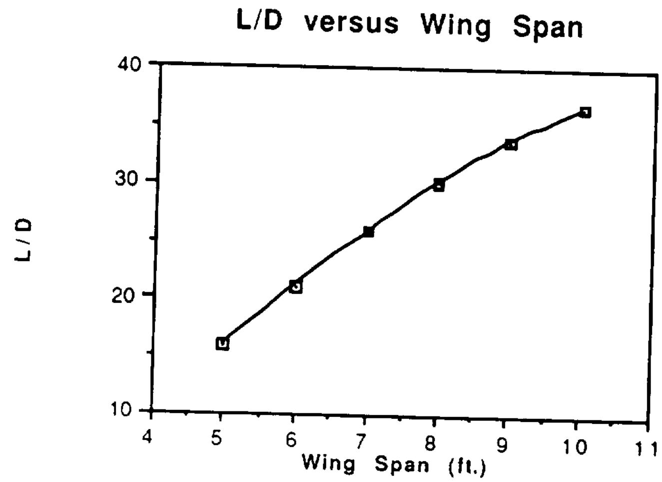
Aeroworld has two gate sizes for its airports, five and seven feet. Thus both five and seven foot wingspans were considered. If a five foot wingspan was employed, two things would have to occur. The plane would need to fly very close to stall in order to achieve enough lift, and the low aspect ratio coupled with the high Cl would cause it to have very poor drag characteristics. The seven foot span with a one foot chord would allow the Pale Horse to fly at a Cl of 0.7, but would require a hinge to fit in the five foot gates. To reduce induced drag further we decided to use an eight foot wing with a 10.5 inch chord, keeping a Cl at 0.7

Figure 4.2



In order to validate the usefulness of extending the span, a trade study was performed. The wings of six planes from previous years were weighed and measured. From this data a linear equation for wing weight versus wing area was obtained (Fig 4.2). Assuming a constant chord of 10.5 inches the aspect ratio, weight, an required cruise Cl were calculated for spans from 5 to 10 ft. The drag was then calculated (for simplicity only the induced drag and skin friction were included, as profile drag remains constant). The L/D was then calculated for each case. From the results plotted in Figure 4.3 it became evident that a larger wing length reduces drag more than increased weight increases drag. Thus, the eight foot span is a viable choice for the Pale Horse.

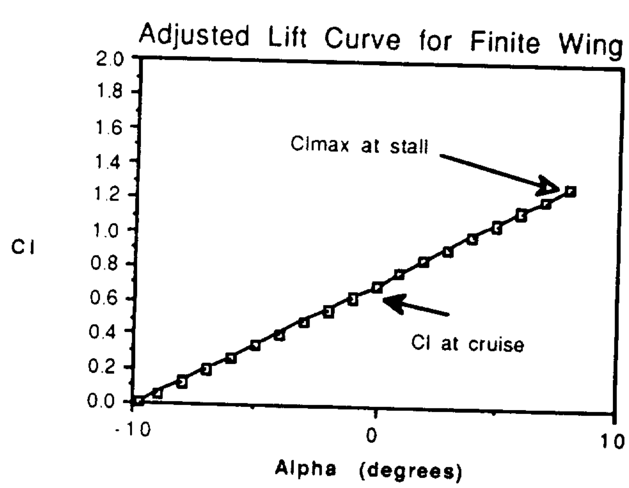
Figure 4.3



Jensen's thesis gives an equation for estimating the Oswald efficiency factor as a function of aspect ratio. With a AR of 9.14 the efficiency factor is approximately 0.78. Correcting the lift slope of the airfoil gives a slope of 4.13/rad.

In order to determine the maximum Cl for the wing it was necessary to use an elliptical lift distribution to approximate the section lift coefficient over the wing. Wings without twist stall at the inboard edges first. For the Pale Horse the inboard sections reach Cl=1.5 at a total wing Cl of 1.3. In order to avoid stall, the max Cl for the plane is 1.3. Using the corrected lift slope gives a stall angle of 13 degrees.

Figure 4.4



In order to cruise at an angle of attack of zero degrees a plane of five pounds weight would require the wing to be mounted at 4.7 degrees relative to the fuselage. This would lower the effective stall angles of the plane to 8.3 degrees. The lift curve slope for the wing is shown in Fig 4.4, corrected for finite wing effects and the wing incidence angle. The wing incidence angle could change for the technology demonstrator if the plane is constructed under the design weight. This would correspondingly improve the stall characteristics of the airplane.

4.3 Drag

The analysis of the drag on the Pale Horse was done using Hoerner's Fluid Dynamic Drag. From the data in this book the individual contributions to Cdo of the wing, fuselage, tail assembly, wheels, and interference and trim effects were calculated. These were then combined using the formula:

$$Cdo = 1/S_{ref} \Sigma C_{D\pi} S\pi$$

For the interference drag a rule of thumb was used that was given by Professor Nelson in Flight Mechanics. The interference drag is equal to about half of the induced drag at cruise.

From this method we determined the parasitic drag breakdown (Fig. 4.5, next page). The fuselage contributed the most to the parasitic drag, at 37.8%, with the wing and interference effects a close second at 24.4% and 22.7%, respectively. Cdo for the entire aircraft, as determined by this method, was found to be 0.048. When the drag contributions are corrected by adding the induced drag (calculated at cruise) to the wing drag term, the percentages change to those in Fig. 4.6 (next page). The wing accounts for 48% of the drag on the total airplane. The drag polar for the Pale Horse is shown on the following page in Fig. 4.7.

FIGURE 4.5

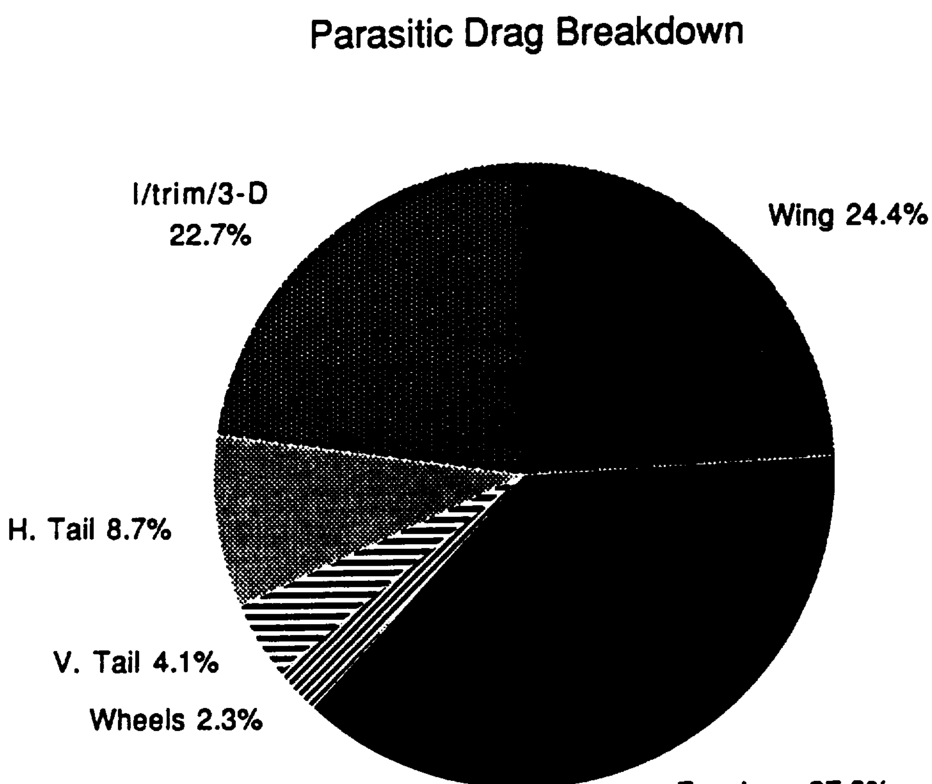

Parasitic Drag Breakdown
I/trim/3-D 22.7%
Wing 24.4%
H. Tail 8.7%
V. Tail 4.1%
Wheels 2.3%
Fuselage 37.8%

Figure 4.6

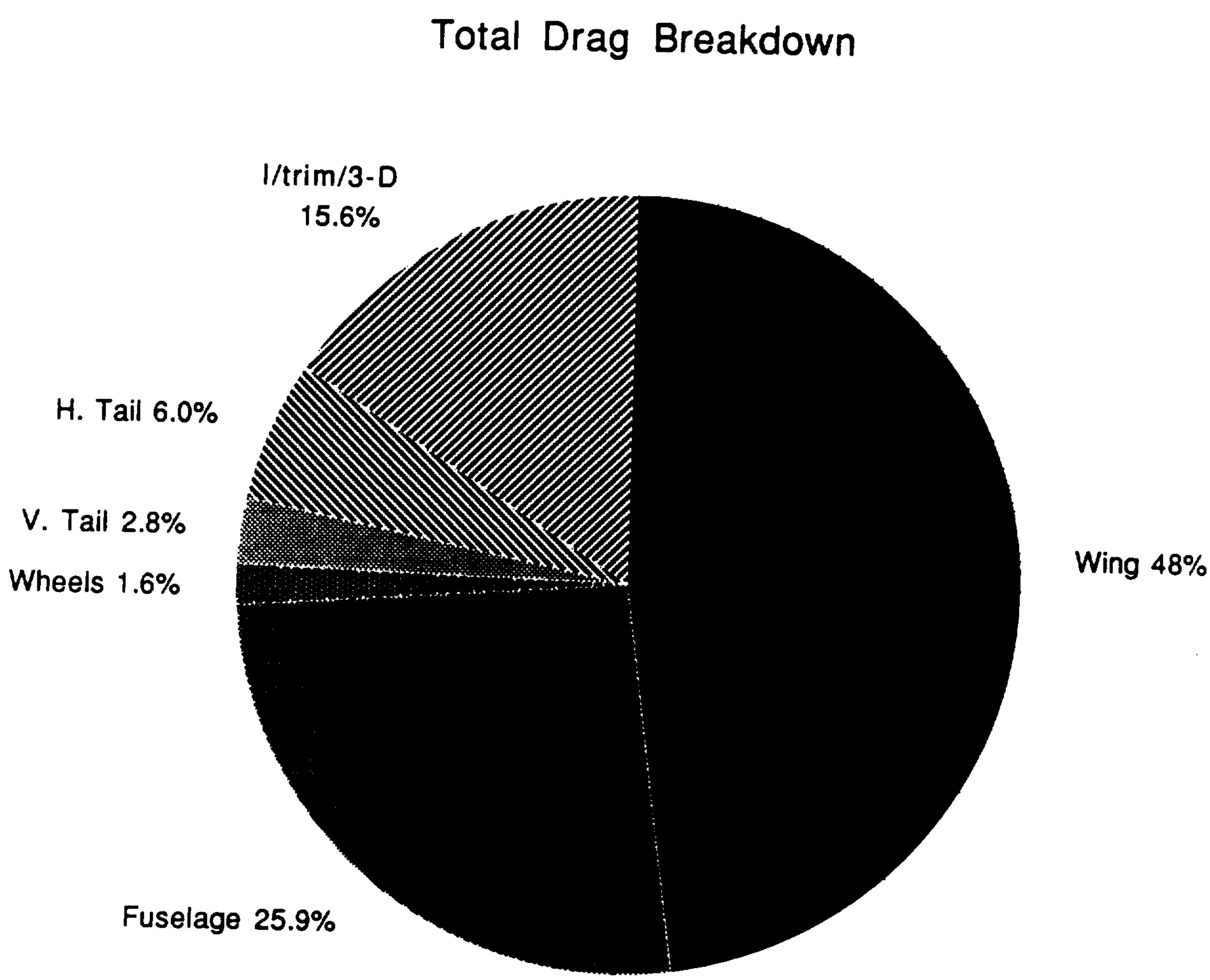
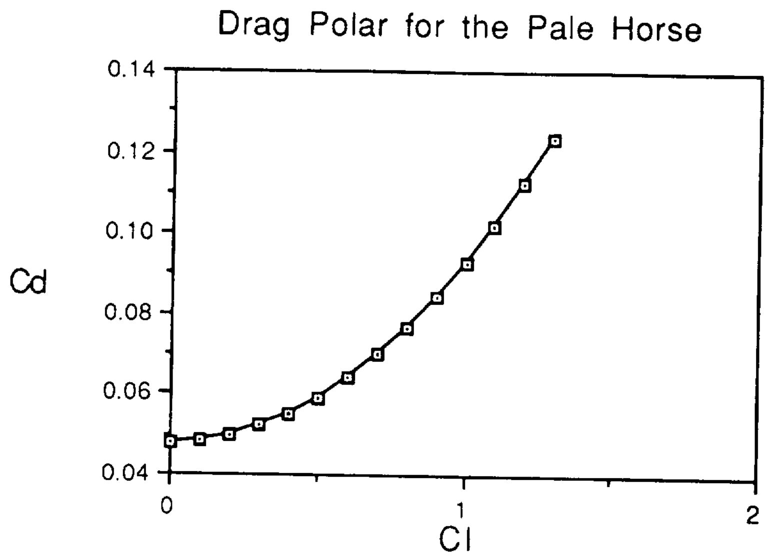

Total Drag Breakdown
I/trim/3-D
15.6%
H. Tail 6.0%
V. Tail 2.8%
Wheels 1.6%
Wing 48%
Fuselage 25.9%

Figure 4.7



At a cruise velocity of 30 ft/s and a Cl of 0.7 the total drag on the airplane is 0.51 pounds. At a Cl of 1.0, which would be used at takeoff or in turning flight, the drag force is 0.71 pounds. It is worth mentioning that by increasing the span of the wing from our original design of seven feet to eight feet with the same wing area reduced the drag at cruise by 13%.

Weights and Structures

5.1 Introduction

As with all aircraft, the Pale Horse was designed to be lightweight and strong. The aircraft has to sustain the forces exerted on it during flight without deforming enough to be catastrophic. To cope with the different stresses, different materials were used corresponding to locations where the stress concentrations were located.

To help reduce drag, sharp edges are reduced as much as possible. This technique explains why the fuselage slowly tapers down to the end of the aircraft and does not immediately taper after the passenger cabin.

Another requirement of the aircraft is that it should break down so it can fit in the traveling box. The eight foot wing folds down to the required length to fit into the box. The fuselage-tail section is able to pack in the box without any dismantling

Although the mission statement did not require it, the group felt that comfort for the passengers should be of importance. It was decided early in the design process that each passenger will have a 2 in. x 2 in. x 2 in. area to do whatever that passenger pleases

Access to the battery pack is of key importance. Placement of the batteries directly beneath the wing reduces the maintenance costs by reducing the time needed to get to the batteries, time to replace them, and time to put the wing back on the plane.

5.2 Wing Structure

Design of the wing consisted of many requirements and constraints. The wing had to be strong, but lightweight. It had to have some dihedral for roll stability of the aircraft. The span had to be sufficient enough to decrease the induced drag to a reasonable value by increasing the aspect ratio. For the wing to be able to fit into the five foot span gates the wing will be hinged so when it is folded the span is exactly five feet.

To make the wing as lightweight as possible, the internals, when possible, were made of balsa wood. The wing was designed and constructed with three spars. These spars are at 5, 25, and 95 percent of the chord, respectively. The leading edge spar is a square cross-section of three-eighths inch balsa wood. The trailing edge spar is triangular in shape with the base being 1 inch and the height being three-eighths. As with the leading edge spar, the trailing edge is made entirely from balsa wood. The main spar for the Pale Horse is a rectangle 1.47 in. by .5 in. thick. This spar, as with the others, is made from balsa. The connecting posts which join the upper and lower surfaces of the wing are made from balsa wood as well. These posts have a cross-sectional area of .0625 in^2. and are spaced evenly throughout the wing.

The Pale Horse was designed and built with 19 ribs evenly spaced except at the hinges. At these hinges there are ribs on either side to support the hinge. The ribs are made of balsa wood. Between these ribs there are quarter ribs to maintain the shape of the leading edge of the wing. The shape is needed to be maintained because this is the region on the airfoil where the greatest pressure difference occurs. These ribs were made by constructing a template from the airfoil points given the the airfoil data book. An airfoil with a 10.5 in. chord was blown up with the help of a photocopier. The airfoil section was traced onto a harder surface from which the shape could then be traced onto balsa wood. A planform view of the half-wing is shown on the following page.

The wing has 10 degrees of dihedral to maintain roll stability. To maintain this angle, supports are wedged under both sides of the wing. These supports are triangular in shape and made from balsa wood. These supports are fastened to the wing. The wing is also mounted at an incidence angle of 4.7 degrees to the fuselage. This angle is maintained through the use of a support wedged under the front part of the wing. This support is also made from balsa wood.

For maintenance needs, the wing on the Pale Horse is completely detachable for access to the battery pack and the avionics. This also enables the wing to be broken down into the required size for travelling needs, and also to be able to load the passengers into the body of the aircraft. The wing is attached through the use of rubber bands which are hooked to knobs attached to the fuselage. This design has been successful in the past and we feel that there is no need to fix something if it is not broken. The mounting of the wing to the fuselage may cut down on headroom in that region of the fuselage, but we feel that we still have more headroom than competing airlines.

Half-Span

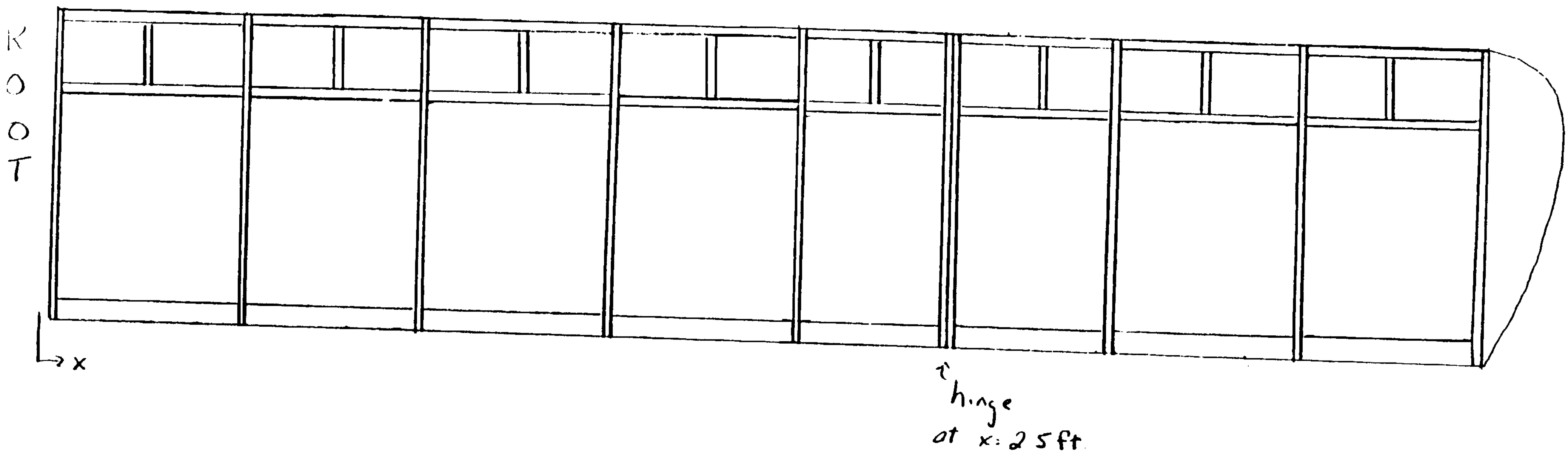


Figure 5.1

To accommodate the five foot gates the hinges are placed 2.5 feet outboard of the centerline mark as noted in the diagram. These hinges are made from spandex stretched over the top of the adjoining ribs and fastened to the sides of these ribs. Three or four clips attach the lower surfaces of the two ribs to prevent the hinge from springing open during flight. The spars have a similar type of hinge adjoining their two sections at this point. The spandex is stretched over the top of the spar and is fastened to both sides. Other than these two points the spars will be solid rods of balsa wood.

Assuming that the lift and the weight are the only significant forces that the wing sees, the bending moment at the root could be calculated using the general equation:

$$M_Z = E^* d\theta_Z / dx^* I_{ZZ}$$

This equation was altered to conform to our geometry. The result was a moment of 5.04 ft-lb.

Initially, the weight of the wing was calculated by developing a rough idea for the design of the wing and then going through and figuring the weight of each component part. Some assumptions had to be made because, for example, the exact area of the ribs and quarter ribs were unknown. The weight of the three spars were found by finding the volume and multiplying by the density. The ribs were modeled by using a rectangular sheet of balsa wood that was 1/8 in. thick and saying the area of the rib was about 70% that of the entire 1.47 in. by 10.5 in. area. The quarter ribs were done in the same manner with the additional assumption that their area was 30% of the 70% stated above. The weight of the monokote covering was known to be 1/4 ounce per square foot. This result multiplied by the monokote weight given above gave the approximate weight of the monokote covering. Using this method the weight for the wing was calculated to be 17.7 ounces. This is almost 22% of the weight of the entire aircraft. However, not included in those calculations were the weight that was cut out of the ribs by removing some of the ribs' interiors, the weight of the connecting posts which join the upper and lower surfaces of the wing, and the weight of the structural supports needed to keep 10 degrees of dihedral and the incidence angle of the wing.

5.3 Fuselage

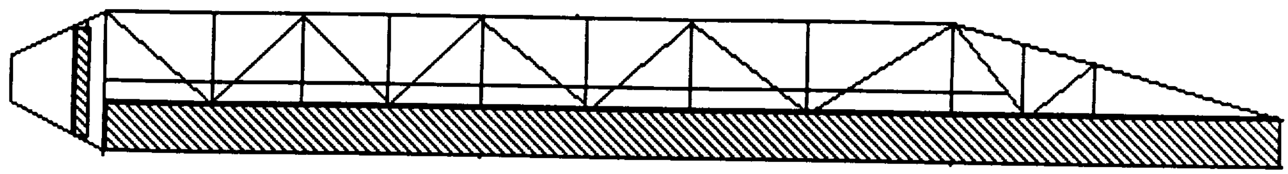
The criteria for designing the fuselage were to minimize cost and weight while maximizing the overall structural integrity and passenger space. As can be seen in figure one the passengers were given a 2x2x2 inch space for seating. With an aisle approximately 2 inches wide, the maximum diameter for the fuselage was 6.5 inches.

The maximum height for the fuselage was 4.25 inches to ensure proper space for the control mechanisms and power supply. Other fuselage characteristics are listed as follows:

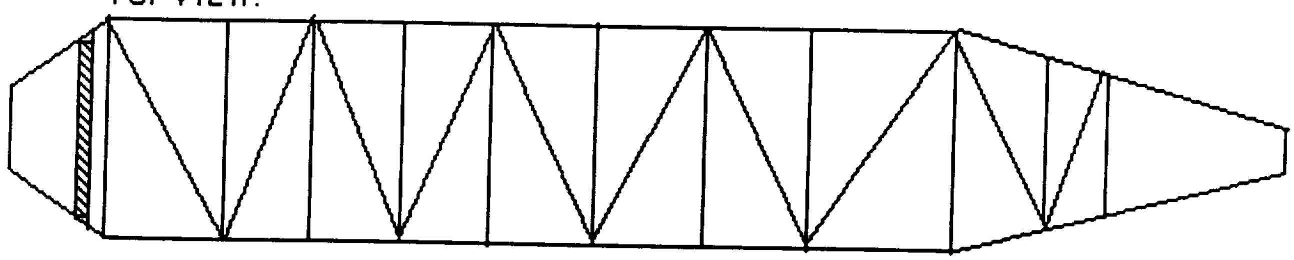
FUSELAGE CHARACTERISTICS:	
Length	51.2 in
Maximum Diameter	6.5 in (PASSENGER SPACES)
Minimum Diameter	1 in (FARTHEST AFT)
Maximum Height	4.25in (PASSENGER SPACES)
Miimum Height	2 in (FARTHEST FORWARD/AFT)
Fineness Ratio	7.87
Total Cost	$22.00
Weight	.83 LBS
Safety Factor	1.5

The fuselage can be considered a frame structure and as can be seen in figure one three longerons run the length of the structure. The main load carrying member of the fuselage is the main longeron or keel. A parametric trade study was performed to size this keel using simple beam bending analysis. Circular and rectangular cross sections for the keel were examined to obtain minimum cost and weight and a safety factor of 1.5. The resulting graphs from this trade study are shown in Figures 5.3-5.4

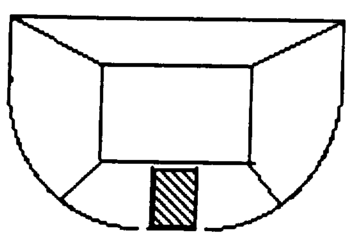
SIDEVIEW:



TOPVIEW:



FRONTVIEW:
FORWARD SECTION



PASSENGER SECTION

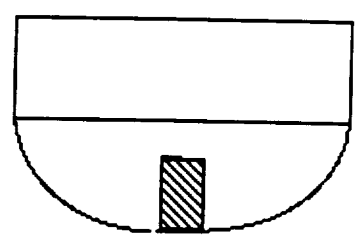
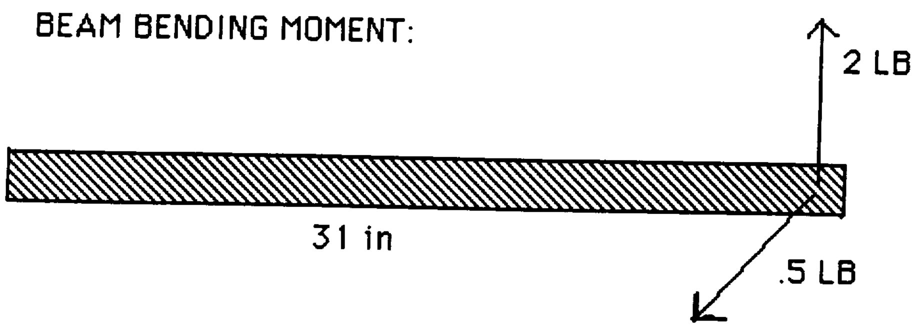


FIGURE ONE

BEAM BENDING MOMENT:



$$\text{stress} = -\frac{M_z\, y}{I_{zz}} + \frac{M_y\, z}{I_{yy}}$$

SYMMETRIC HOMOGENEOUS ADVANCED BEAM

FIGURE 5.2

Figure 5.3

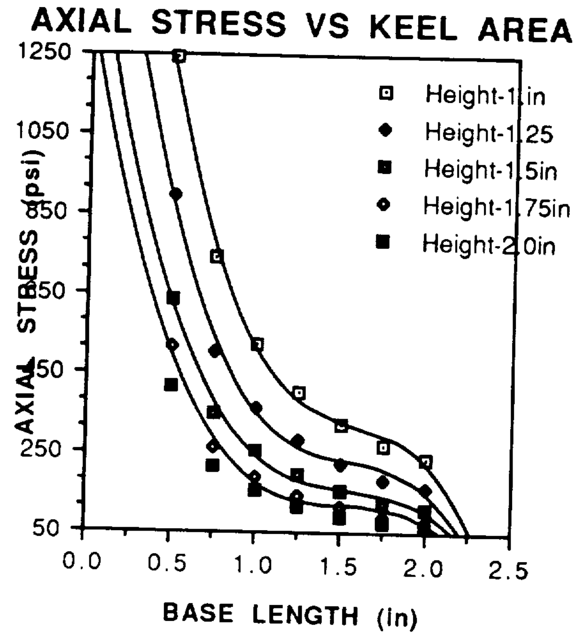
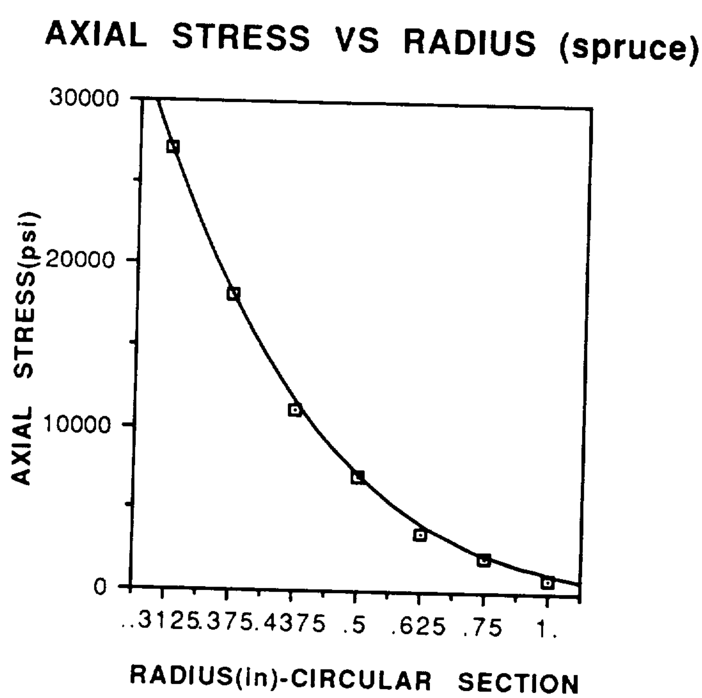


Figure 5.4



The main loads considered to act on the keel were those created by the empennage control surfaces. These ultimate loads, as can be seen in figure two, were calculated in the extreme case where the rudder was deflected at an angle of 20 degrees and the elevator was deflected at an angle of 20 degrees. The range of axial stress for the various sizes of the keel examined can be seen in plots one and two. Using this information, a rectangular keel cross section was chosen having a height of 1.25 inches and a width of 1 inch.

The fuselage is curved and tapered to minimize skin friction drag. The curved ribs were designed along with the two other longerons and cross beams to ensure the fuselage shape. Since the keel is designed to carry the main loads, these members could have a minimum cross sectional area to minimize the overall weight of this structure.

Some overhead sections of the fuselage were made removable for passenger entry and battery maintenance. These sections were attached using rubber bands so that the sections could be removed easily. A section of the passenger deck was also made removable so that the batteries and control mechanisms could be accessible.

The engine block was designed to withstand a static thrust of 2.6 lbs. To withstand this load the supporting beams of the engine block were made of spruce. The block itself was made of 1/2 inch thick balsa wood to minimize weight.

The landing gear for the Pale Horse is a tail-dragger. This type was selected so the wing will already be at an angle of attack of 8.7 degrees during takeoff. Using a moment balance between the weight acting at the center of gravity and the thrust acting at the centering, the position for the front tires was found. This position is one inch behind the propeller. The struts of the main landing gear are long enough so that the propeller clears the ground by one and a half inches. This means the height of the lower surface of the airplane above the ground is four and one half inches. The wing at this position is at eight and one half inches above the ground. There should not be any significant ground effects. The tail dragger is connected to the bottom of the fuselage at the very end of the plane. The tail dragger initially was to be connected to the rudder to give better ground handling qualities, but the extra weight conflicted with the results from the stability aspect. The struts for the landing gear are made of aluminum. A wire is connecting the main landing gear to give more support for hard landings. The struts are connected to the keel of the fuselage.

5.4 Empennage

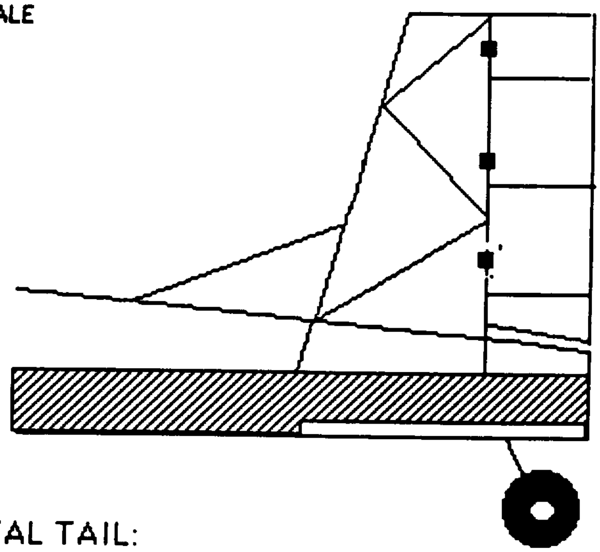
The empennage, as seen in Figure 5.5, consisted of a vertical and horizontal flat plate which were directly connected to the keel to ensure that the control surface loads are adequately supported. Both surfaces were notched to ensure adequate control surface deflection and a dorsal fin was included to help with roll control.

The structure consisted of 1/4x1/4 balsa wood sections. The hinge connections were critical areas in the empennage since spaces in these sections would affect elevator and rudder effectiveness. These spaces were limited as much as possible by using curved balsa wood sections along the hinge connections.

The horizontal surface was mounted at an angle of incidence of +2 degrees. The surface was mounted as low as possible in relation to the wing to avoid as much of the wake created by the wing as possible. This would ensure a tail efficiency as close to unity as possible. This surface was also tapered as much as possible in relation to the control surfaces to decrease the root bending moment created.

VERTICAL TAIL:

NOT TO SCALE



HORIZONTAL TAIL:

NOT TO SCALE

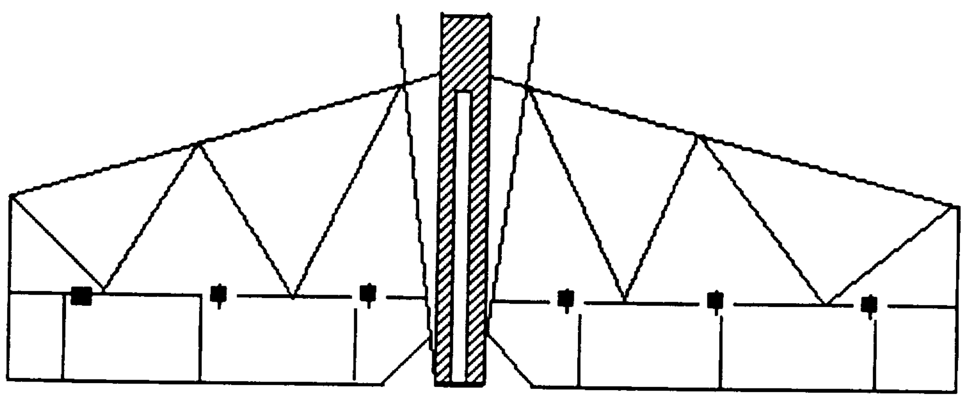
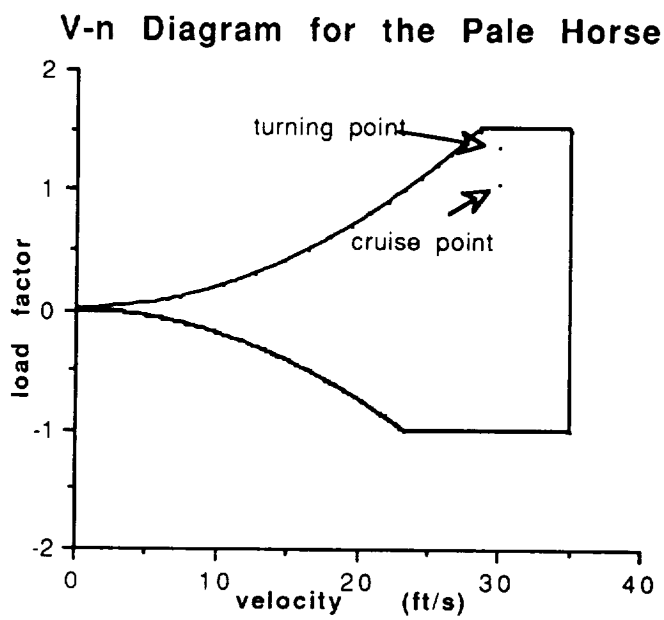


Figure 5.5

5.5 V-n Diagram

Using FAR 25 as a guideline, the maximum load factor desired for the Pale Horse is 1.5. We did not deal with the yield load factor because this is a transport aircraft and not a military fighter jet and there is no need to fly at the limits. Using this knowledge, all structural components were sized toward this goal.

Figure 5.6



The cruise point and the turning point, indicated in Figure 5.6 with the V-n diagram, were calculated from the known data for those points. Even at the turn, there is still enough difference between the maximum load factor and the actual load factor to have a reliable buffer, or error, margin.

5.6 Center of Gravity

To insure static stability, 5.8 in. from the leading edge is the absolute aft position for the center of gravity. Initial calculations located the center of gravity aft of this position. With some innovative maneuvering of these internals, the battery pack and the avionics, this location moved forward. All final positions were made in order to move the center of gravity as far forward as possible. Also the vertical position of the center of gravity had to lie along the aircraft centerline as much as possible. If this was off centerline the aircraft could tip over during takeoff. The final internal configuration had to abide by the following rules:

1) The engine's battery pack is split into two groups. The first is a block of 7 batteries abreast on the payload level. The second is a block of 6 batteries abreast below the payload level. These groups are both directly behind the wall the engine is mounted on.
2) The receiver and the system battery are abreast as well. Both lay on t heir sides and are behind the lower batteries.
3) The two servos controlling the elevator and the rudder are aft of the receiver and system battery and are also abreast.
4) The speed controller is attached to the lower surface of the payload's loor and is above the two servos.

The final center of gravity location was calculated by breaking the aircraft into its major component parts. The component weight was multiplied by the X or Y position of the component's center of gravity. It was assumed that the centers of gravity for all components acted at the center of that component. All products of this multiplication were added and then divided by the total aircraft weight.

The travel of the center of gravity location was only a function of the payload. Burning of fuel in this case did not change the weight since we used an electric motor. Only the two extremes cases were analyzed to get the range of travel for the center of gravity.

Some error can be attributed to this method of finding the center of gravity. Wires connecting the batteries to the engine and the system battery to the avionics can prevent the components from being in the exact place they should be.

<u>CENTER OF GRAVITY OF THE PALE HORSE</u>

	Including payload	Empty
X:	3.79 in. from L.E	3.38 in. from L.E.
Y:	2.03 in. from lower surface	2.00 in. from lower surface

5.7 Weights

Our design requirement stated that our goal for the weight of the Pale Horse was 5 pounds. It was easy enough to weigh the avionics components. The motor, engine mount, propeller, servos, speed controller, receiver, landing gear, and the system battery were weighed on a triple beam balance. The weights for the payload and engine battery pack were calculated from the given dimensions for 1 person(ping-pong ball) and 1 battery.

The major unknown weight was the structural weight. To obtain this weight, the aircraft was separated into 4 structures - wing,horizontal tail, vertical tail, and the fuselage. Plodding through the structure piece by piece yielded the weights for each. The following chart, Table 5.1, shows the weight breakdown for the Pale Horse.

Table 5.1

Component	Weight (lb)	Total Weight (lb)	Weight Percentage
Fuselage	.83	4.98	16.57
Horizontal Tail	.08		1.61
Vertical Tail	.04		0.72
Wing	1.10		22.13
Motor	.57		11.40
Servo 1	.04		0.75
Servo 2	.04		0.75
Payload	.18		3.65
Batteries	1.38		27.71
Landing Gear	.30		6.02
Receiver	.06		1.18
Sys. Battery	.13		2.51
Engine Mount	.07		1.46
Speed Controller	.11		2.23
Propeller	05		0.98
Tail Dragger	.02		0.36

5.8 Materials Selection

The criteria used for selecting the material for the Pale Horse was strength, weight, availability, cost and machinability. With these factors in mind the main structure of the fuselage, wing and tail was composed of wood. All of the wood chosen was balsa except for the main supporting cross beams of the engine block which was composed of spruce to withstand the 2.3 lbs of engine static thrust.

Wood was chosen over the other materials using the following ranking system:(1=highest rank in category)

	Strength	Weight	Cost	Availability	Machinability
balsa	4	1	1	1	1
spruce	3	2	2	2	2
composites	2	3	3	4	3
alloys	1	4	4	3	4

As can be seen both types of wood considered ranked the highest in all categories except for strength. This lack of strength in comparison to the other categories of material could be overcome with proper engineering application.

The skin of the fuselage, wing and tail was composed of colored Monokote. Monokote is light(1/4 oz/ft^2), available, affordable and easy to work with.

Other materials used in the structure of the Pale Horse were rubber bands for the connection of the removable fuselage, wing and passenger deck, epoxy and tape.

Propulsion

6.1 Introduction

The propulsion system of the Pale Horse must satisfy the following criteria:

(1) Minimum range of 19,000 ft. per day (8 flights each day an average distance of 2,150 ft. plus a 10% safety factor).
(2) Take off distance not to exceed 60.0 ft. (Prefer take off distance of less than 37.5ft - length of shortest runway in Aeroworld)
(3) Cruise velocity of 30 ft/s.
(4) Rate of Climb between 5 ft./s and 10 ft./s.
(5) Minimize weight.

The primary considerations for the propulsion system of the Pale Horse are power and range. The power requirement for the Pale Horse is concerned with insuring that the aircraft has enough power to take off in the allotted distance and cruise at the recommended cruise velocity of 30 ft/s. The aircraft requirements of a cruise range greater than 19,000 ft. allows the airline to change the battery once a day instead of after every flight. This allows for quicker flight to flight turn over and saves on aircraft maintenance costs. These factors are the most important considerations in the design of the propulsion system for the Pale Horse. The overall cost of operation depends greatly on whether these considerations have been met.

The propulsion system consists of the motor, the propeller, and the batteries, all of which affect the range and power of the aircraft. The following three sections will each deal with one of the components of the propulsion system. The data in these sections is based on the initial aerodynamic estimations of sizing and performance of the Pale Horse.

Aircraft weight	5.0 lb.
Cdo	0.025
efficiency	0.85
AR	9.14
S	7.0 ft^2

Section 6.5 consists of the final propulsion proposal which gives updated propulsion data calculated from the refined aircraft information. The major sources of data generated in this section were the programs Electric Prop. and Takeoff Performance that were distributed by Prof. S. Batill. Example output from these programs can be found in the Appendix.

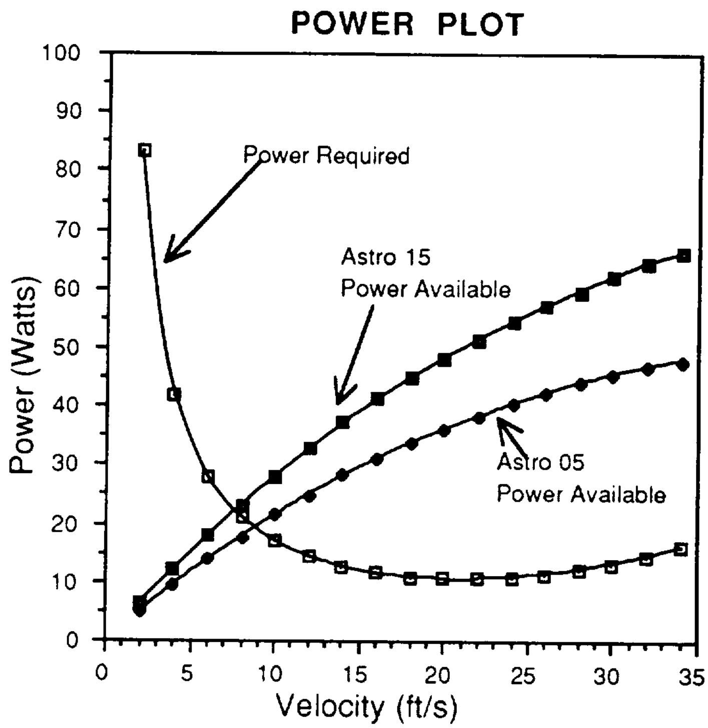
6.2 Motor

Because the motor subcontractor needed to be chosen early in the design process, the motor was the first component of the propulsion system studied. Studies of previous RPV designs showed that the target weight of 5.0 lbs. for the Pale Horse would need either the Astro 05 electric motor or the Astro 15 electric motor to fulfill the propulsion system requirements. Motor power and static thrust were the driving factors which dictated the decision between the two motors.

	Astro 05	Astro 15
Voltage	8.4 volts	14.4 volts
Kt	0.616 in*oz/amp	1.084 in*oz/amp
Kv	0.00041 volt/rpm	0.00079 volt/rpm
Max. ROC	4.7 ft./s	7.0 ft./s
Max. RPM	19,500	18,500
Batteries	7 batteries	12 batteries
	1.2 volts each	1.2 volts each

Figure 6.1 is the power required vs. power available plot for both the Astro 15 and the Astro 05 motors in a sample study using the Tornado 10-6 propeller. In this case, as in all the other tested propeller cases, the Astro 15 delivers more power than the Astro 05 by approximately 30% to 40%. The advantages of the higher power include a shorter take off distance, greater maneuverability with the greater rate of climb and less strain on the motor at cruise. The major advantage of the Astro 05 is the lower weight of both the motor and the batteries which can increase range and decrease takeoff distance. The Astro 15 offers a larger range for error if the power required is higher than originally calculated or if a battery problem causes the maximum voltage to be lower than expected. The power available and the rate of climb for the Astro 05 have a chance of being raised to the acceptable range if the weight of the aircraft is reduced or with the use of a larger propeller.

Figure 6.1



In analyzing the motor data for the Astro 05, it was decided that the hopes of decreasing the aircraft weight enough to get an acceptable rate of climb of greater than 5.0 ft./s is not a realistic hope. On the other hand, if the structure of the Pale Horse ended up weighing significantly more than the predicted value, the Pale Horse would be under powered for its design requirements and objectives. The high power available, the high rate of climb, the large area for error, as well as the versatility in propeller choices for the Astro 15 show that it is the best choice for the motor of the Pale Horse.

6.3 Propeller

The propeller for the Pale Horse is to operate near its maximum efficiency at cruise velocity, produce high enough thrust to take off in less than 60.0 ft., and aid in meeting the minimum cruise range with the smallest battery available.

Figure 6.2

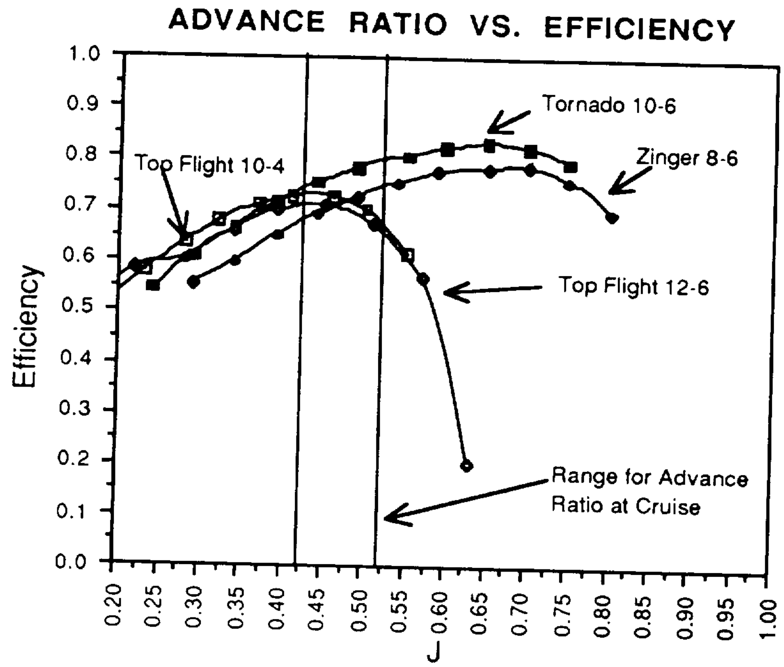


Figure 6.2 is the advance ratio vs. efficiency plot for each of the propellers that were considered. The data for this plot was gathered from the propeller program on the Apple computer in the Aerolab. The group of tested propellers was selected because of their availability through a nearby dealer. The plot shows that all the propellers are near their max efficiency in the estimated region of cruise advance ratio. A trend in propeller performance is that as weight decreases, the advance ratio increases. Because it is believed that the final aircraft design will weigh less than the 5.0 lb. initial estimate, a propeller should be chosen that has a positive slope in the region of cruise advance ratio. The positive slope insures that as the aircraft weight decreases, the efficiency increases. The efficiency plot shows that the Top Flight 10-4 and the Top Flight 12-6 have unfavorable negative slopes. The Tornado 10-6 and Zinger 8-6 propellers, with the high efficiencies and the positive slopes in the range of cruise advance ratio, have the more favorable performance.

The thrust produced by each propeller is most dependent on the propeller pitch, diameter, and RPM. Trends that materialized in this study include a higher propeller pitch and a larger propeller diameter produce greater thrust while shortening the takeoff distance and the cruise range. The propeller, in conjunction with the Astro 15 electric motor, must be able to attain lift off in less than 60.0 ft. but it would be preferred to have a take off distance of less than 37.5 ft., the length of the shortest runway in Aeroworld. Including a 10% safety / error factor, the aircraft should be designed to take off in less 33.8 ft. so the maximum take off length including the safety factor would be 37.5 ft. Careful attention must be paid to getting too short of a takeoff distance because of the high stresses that can be produced by the very rapid acceleration to take off velocity. It was estimated that any take off distance less than 23 feet created a high risk of structural damage to the wing.

Propeller	Take off Distance (ft.)
Zinger 8-6	(Greater than 60.0 ft.)
Top Flight 10-4	42.3 ft.
Tornado 10-6	38.2 ft.
Top Flight 12-6	21.8 ft.

The data concerning each of the proposed propellers running on 14.4 volts, shows that the Zinger 8-6 is insufficient because of the lack of thrust at take off, which causes the large take off range. The remaining propellers are within an adequate range of takeoff distances. Because the Top Flight 10-4 did not have a favorable efficiency plot it is believed that the two remaining propellers are more adequate. The Top Flight 12-6 produces a great amount of thrust with less of a cruise range. The Tornado 10-6 provides a longer cruise range with a smaller thrust. Final consideration of the propeller is dependent on the voltage and capacity of the battery pack.

6.4 Batteries

The battery pack for the propulsion system has a great deal to do with determining the available thrust, the range, and the overall weight of the aircraft. The Astro 15 motor is rated to run on a 12 cell, 16.2 volt battery pack. It has not been possible to find a battery pack that fulfills the above criteria. Because of this, two battery packs have been substituted for consideration - a 12 cell, 14.4 volt pack and a 13 cell, 15.6 volt pack.

Propeller	Take off (14.4 volts)	Take off (15.6 volts)
Top Flight 10-4	42.3 ft.	34.9 ft.
Tornado 10-6	38.2 ft.	32.2 ft.
Top Flight 12-6	21.8 ft.	17.6 ft.

The above table shows that the 12 cell, 14.4 volt pack gives reasonable takeoff distance for the Top Flight 12-6 propeller. The 13 cell, 15.6 volt pack improves the takeoff distance of the Top Flight 12-6, as well as brings the Top Flight 10-4 and the Tornado 10-6 close to the preferred take off distance. The increase in the battery pack voltage will not affect the cruise of the aircraft because the motor will be throttled back during cruise which will lower the average voltage across the motor. The only significant change from 14.4 volts to 15.6 volts will be the increase in thrust which will be accompanied by a slight increase in weight because of the extra battery. It is believed that the increase in the weight can be more than adequately compensated for the extra thrust produced at take off with the 15.6 volts. With this data, a smaller propeller can obtain shorter take off lengths while maintaining its cruise range. For this reason the 13 cell, 15.6 volt battery pack is best used with the Tornado 10-6 propeller while the 12 cell, 14.4 volt battery is best used with the Top Flight 12-6 propeller.

The greatest factor in determining the aircraft range is the battery capacity. The batteries must have a large enough capacity to survive taxiing to the runway, delays in takeoff, the takeoffs themselves, and taxiing to the gate after landing. For these calculations it was estimated that 15% of the battery capacity will be used for the above list of maneuvers. Therefore, when total range calculations were performed for cruise range, only 85% of the battery capacity was used. The three battery capacities that were studied were 0.6 amphr, 0.9 amphr, and 1.2 amphr.

Total Capacity	Ground Maneuvering Capacity	Cruise Capacity
1.2 amphr	0.18 amphr	1.02 amphr
0.9 amphr	0.135 amphr	0.765 amphr
0.6 amphr	0.09 amphr	0.51 amphr

The advantage of the lower capacity batteries is that the weight of the aircraft can be cut by 0.3 lbs. to 0.8 lbs. depending on what capacity is utilized. The weight that is saved with the smaller batteries can be either put towards improving the structures of the aircraft or can be left off to help aid in the increase in the overall cruise range and the shortening of the takeoff distance.

Figure 6.3

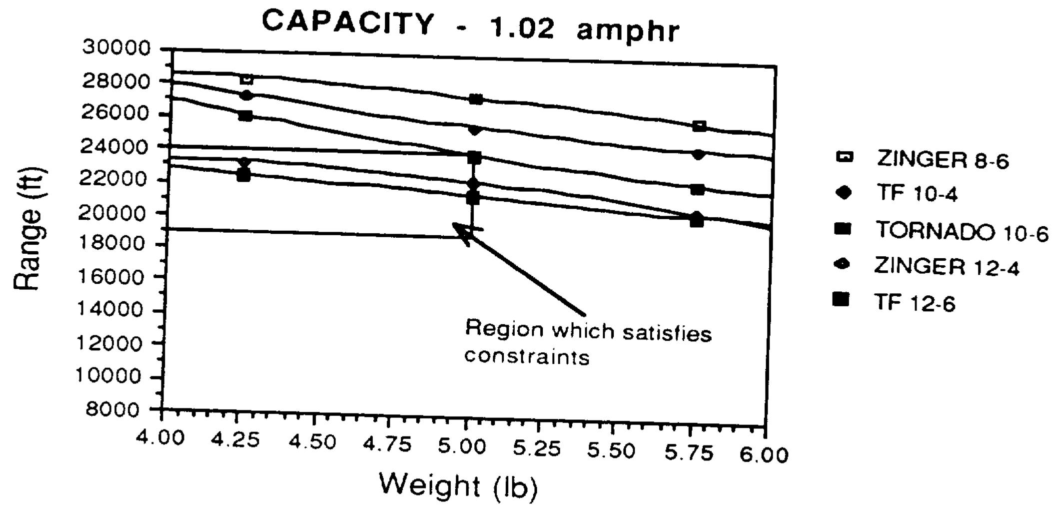


Figure 6.4

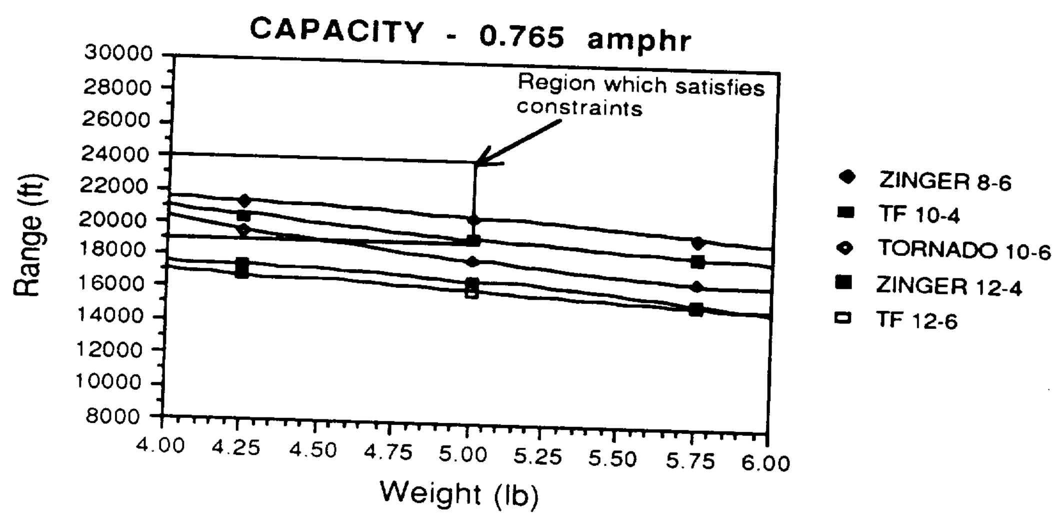


Figure 6.5

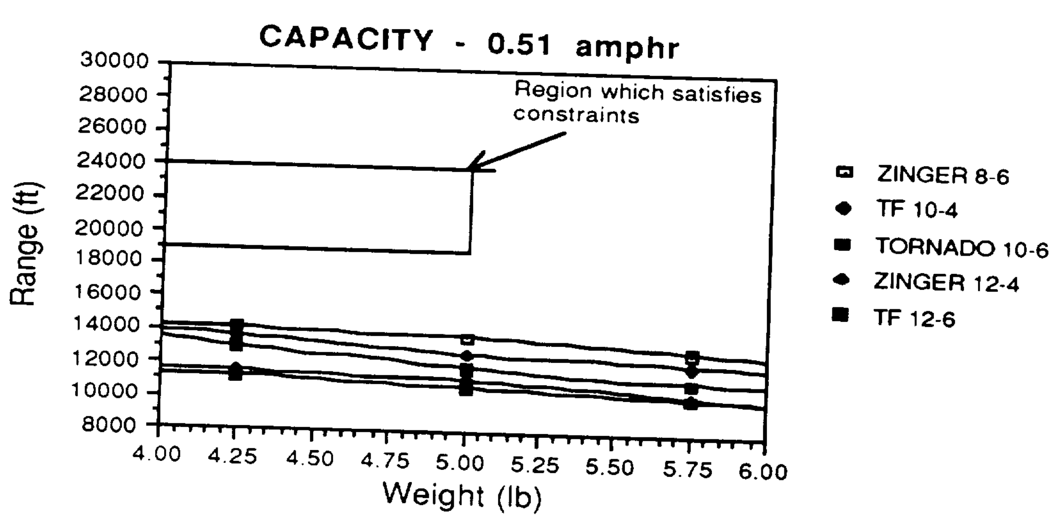


Figure 6.3 though Figure 6.5 show how the range of the aircraft varies with various battery capacities, propellers, and aircraft weight. These plots demonstrate that the battery capacity is the most important variable in determining the range of the aircraft. The 0.6 amphr battery can easily be ruled out because it does not have enough "juice" to get near the required overall range. Looking at the the 0.9 amphr and the 1.2 amphr batteries show that a smaller diameter propeller will give longer range than a longer propeller, but the longer propeller produces greater thrust which is needed for take off.

6.5 Final Propulsion System Performance

Taking all the above information into consideration, it has been decided that the finalized propulsion system will consist of the Tornado 10-6 propeller attached to the Astro 15 electric motor which is being driven by 13, 1.2 volt / 1.2 amphr batteries and produces a static thrust of approximately 2.3 lbs.

Astro 15 Electric Motor	Weight	10.24 oz
	Gear Ratio	2.21
	Kt	1.084 in-oz/amp
	Kv	0.00079 volt/rpm
Tornado 10-6 Propeller	Weight	4.0 oz.
	Diameter	10.0 in.
	Pitch	6.0 in.
13 P-120SCRP Batteries	Tot. Weight	22.1oz.
	Tot. Voltage	15.6 volts
	Capacity	1.2 amphr

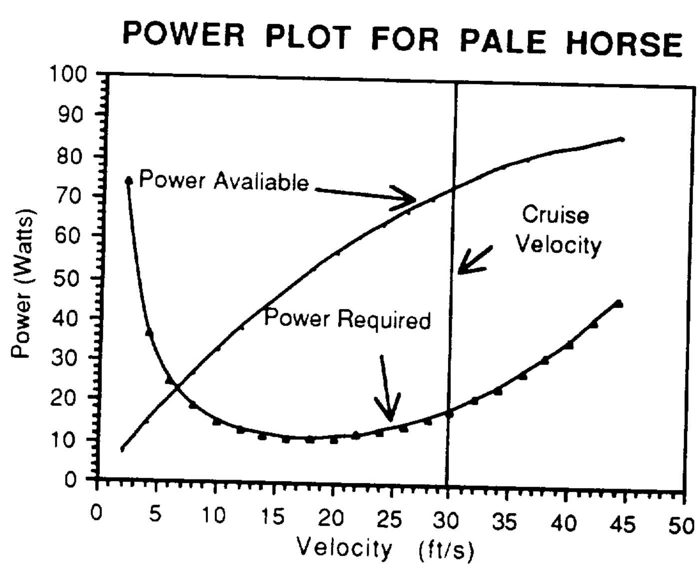
Along with these components are the cabling, tape, and control rods which connect the speed controller to the Astro 15 which allows for the speed and thrust variations needed for flight maneuvering. This propulsion system generates the following cruise data.

Cruise Data

Velocity	30 ft/s
Voltage	9.3 volts
Current Draw	5.5 amps
Motor RPM	10,200 rpm
Propeller RPM	4,615 rpm
Power	20.7 Watts
Advance Ratio	0.468
Propeller Efficiency	0.76
Total Range	20,000 ft.
Total Flight Time	11.1 min.
Ct	0.075
Cp	0.046

Figure 6.6 is a power available vs. power required plot for the finalized propulsion system with the refined aircraft estimates.

Figure 6.6



Stability and Control

7.1 Introduction

To ensure smooth flight and proper handling of the Pale Horse, a thorough analysis was done in the area of stability and control. This section will address the sizing of the empennage for longitudinal and lateral stability; the actuation of roll stability; the sizing of the control surfaces; and the center of gravity effect on the handling qualities.

The Pale Horse has a standard empennage, using a low horizontal tail with a single vertical tail for stability. Both surfaces are flat plates. Control surfaces consist of a rudder and an elevator, each sized to accomplish the flight maneuvers dictated by our mission. The aircraft has no ailerons, and depends on the high-wing dihedral and a dorsal fin mounted to the fuselage and vertical tail for roll stability.

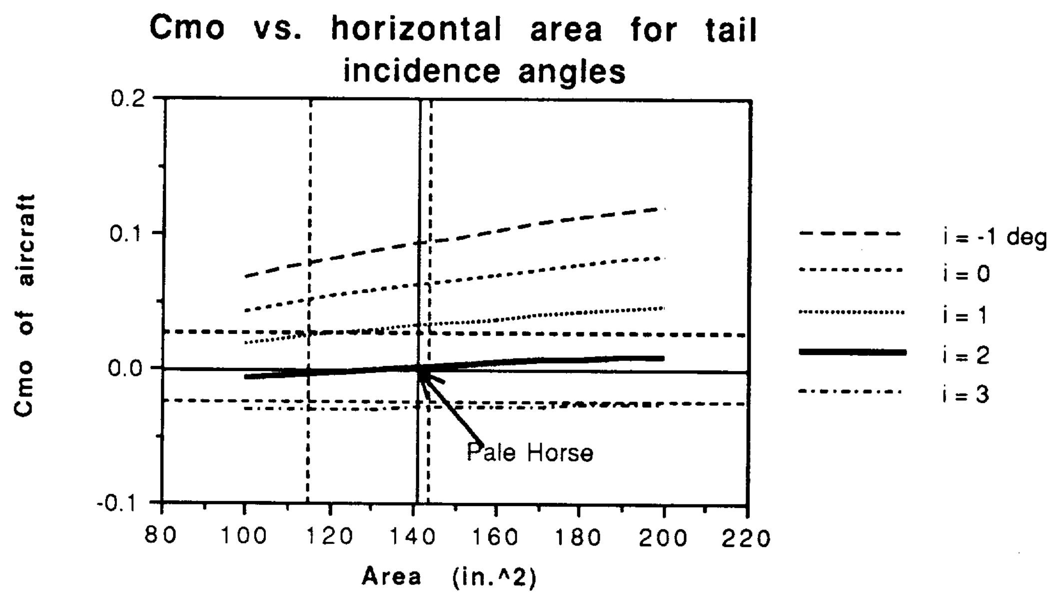
Static stability was the first concern in the placement of the center of gravity, and placed a forward limit on its position. This is explored further in the section on weight analysis for the Pale Horse. A neutral point was established, limiting the center of gravity in the aft direction. For desirable handling qualities for the aircraft, the static margin was set at 15% for a loaded aircraft, and, as the center of gravity travels, the margin increases to 20%, also acceptable.

7.2 Horizontal Tail

The horizontal tail was sized to provide a stabilizing moment about the center of gravity during all flight maneuvers. Initial sizing was done with a Macintosh application called LinAir 1.49. This program uses a lifting line approximation from the Kutta-Jukowski Theorem to determine the aerodynamic forces of aircraft at various angles of attack. LinAir requires a data file for the elements of consideration. We modeled our aircraft for this program with four elements: the wing , horizontal tail, vertical tail, and landing gear. Wing data was produced by the aerodynamics group, as were the drag polars for each element. The horizontal tail data was varied to determine the crucial parameters of longitudinal stability. The tail incidence angle as well as the span and area had the most effect.

By varying the center of gravity and developing carpet plots for Cm versus area for different values of incidence angles, trends were established. Figure 7.1 shows the plot with the center of gravity located at 3.83 inches from the leading edge. After specifying a horizontal tail volume ratio range of .4 to .5, (Reference 11), and allowing ± .025 for Cmo, (the pitching moment), at cruise, an acceptable region could be plotted. The value of the horizontal area for which Cmo equals zero could then be selected.

Figure 7.1



The Pale Horse was therefore sized with a horizontal tail area of 140.25 square inches, spanning 22 inches, and with a taper ratio of .7. With this established, calculations could be performed in terms of the stability coefficients.

Trade studies were also completed to determine the length of the tail as well as its mounting angle. As the horizontal tail area and/or the horizontal span increased, Cmα, (the pitching moment at various angles of attack), becomes more negative. It was also noted that as the center of gravity travels aft, Cmα becomes more positive, requiring a larger tail incidence angle to compensate. It was found that, although taper did little to affect the aerodynamics of the horizontal tail, it did decrease stresses. By tapering the leading edge of the flat plate, the bending moments at the root chord were reduced.

7.3 Pitching Moment

We required the Pale Horse to have a pitching moment coefficient at cruise, (C_{mo}), greater than zero to ensure trim at a positive angle of attack, (referenced to the fuselage). In addition, the slope of the pitching moment versus angle of attack, ($C_{m\alpha}$), had to be negative for aerodynamic stability. The three elements of pitching moment consideration were the wing, the fuselage, and the horizontal tail. By determining the other effects, the horizontal tail incidence angle could be established to accomplish steady flight.

The wing effects on the pitching moment were calculated using the following:

$$C_{mo_w} = C_{mac_w} + C_{lo_w}(X_{cg}/c - X_{ac}/c)$$
$$C_{m\alpha_w} = C_{l\alpha_w}(X_{cg}/c - X_{ac}/c)$$

where C_{mac_w} and $C_{l\alpha_w}$ were determined by airfoil characteristics.

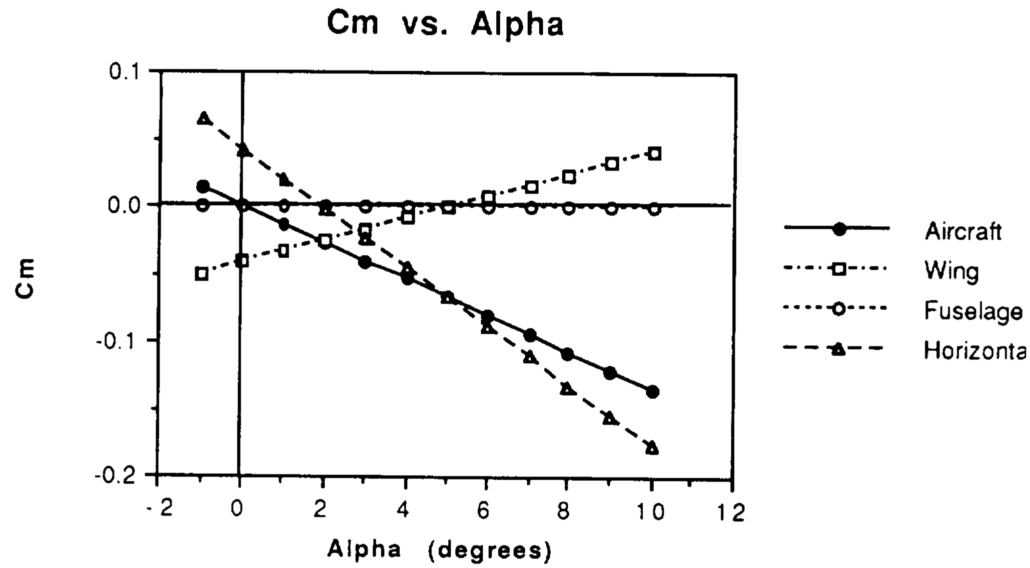
The fuselage effects were determined using Multhopp's method. This method uses momentum and energy relationships and accounts for the induced flow along the fuselage due to upwash and downwash from the wing. C_{mo_f} and $C_{m\alpha_f}$ were calculated for the Pale Horse.

Assuming the dynamic pressure ratio between the wing and the horizontal tail was approximately one, contributions were calculated by:

$$C_{mo_t} = V_h C_{l\alpha_t}(\varepsilon_o + i_w - i_t)$$
$$C_{m\alpha_t} = -V_h C_{l\alpha_t}(1 - d\varepsilon/d\alpha)$$

where ε and $d\varepsilon/d\alpha$ were the downwash effects. The pitching moment curves for the Pale Horse may be seen on the following page in Figure 7.2, as calculated from reference 10. A numerical representation of these calculations may be seen in the summary table

Figure 7.2



7.4 Vertical Tail

In sizing the flat vertical tail for directional stability, we found no analytical expressions for calculating the dimensions. We determined from Reference (Reference 11) that a desirable volume ratio would be .22. This equated to an area of 66.53 square inches. The yaw angle coefficient was calculated using:

$$Cn_{\beta t}=V_V Cl\alpha_V(1+d\sigma/d\beta)=.66/\text{radian}$$

where $d\sigma/d\beta$ is the sidewash effect. The fuselage effect on $Cn\beta$ was considered as well, but was negligible due to a very small wing-body interference factor. A positive coefficient denotes static directional stability for the Pale Horse.

Similar to the horizontal tail, the vertical tail has a span of 11 inches and a leading edge taper of .6. The taper allows the larger root chord to be mounted to the fuselage, providing a sturdier surface. Please refer to the summary table for the list of results.

7.5 Roll Stability

Since the Pale Horse will be flying at low velocities, it was determined that the rudder, with airfoil dihedral, would be able to provide enough turning power to bank the aircraft without ailerons. Not only does this decrease the weight of our structure, it also simplifies control. One problem which does arise, however, is the question of roll stability. In a turning configuration, the aircraft must have a stabilizing moment to counter the roll caused by rudder deflection. The Pale Horse is thus a high-wing aircraft in order to utilize the stabilizing effects caused by the flow around the fuselage. There is also a dorsal fin mounted between the fuselage and the vertical tail which will aid in the fuselage contribution. The aircraft utilizes wing dihedral to produce additional roll stability. This angle Γ was determined from the relationship:

$$\Delta\alpha=\arctan(\sin(\beta)*\tan(\Gamma))$$

where $\Delta\alpha$ is the change in angle of attack during a maneuver. This term was limited by the aerodynamics of the aircraft, while the yaw angle β was determined from the expression:

$$\beta=Cn\delta r*\delta r/Cn\beta$$

This allowed us to size the dihedral angle at 10 degrees.

Since we are using a hinged wing in our design, we elected to give the Pale Horse a straight V dihedral rather than polyhedral or parabolic. This will enable us to be more precise in the construction of the technology demonstrator by simplifying the structure.

7.6 Elevators

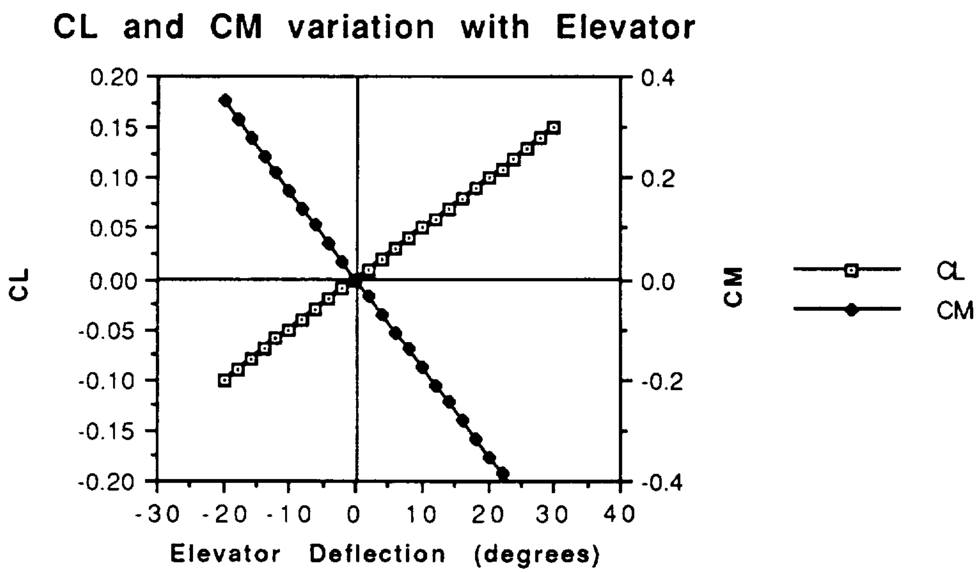
The Pale Horse will use elevators to control longitudinal motion. Sizing criteria for the control surfaces included the ability to rotate the aircraft after take-off and to trim at high angles of attack during landing. The elevator effectiveness parameter was approximated by the following equation:

$$\tau_{max}=-(Cm_{\alpha}\alpha_{max})/(V_h Cl\alpha_t \delta e_{max})$$

where α_{max} was limited by airfoil characteristics and δe_{max} was estimated to be ±20 degrees. By studying the trade-offs between aerodynamic stability and the control power, t_{max} was selected to size the elevators at 2.5 inches by 22 inches spanwise.

This resulted in a $Cl\delta e$ of .286 /radian and a $Cm\delta e$ of -1.00 /radian, both of which are desirable values. As the elevators are deflected downward, the lift due to the tail will increase, causing the nose to drop and a more negative longitudinal moment to occur. Refer to Figure 7.3 for a graphical representation.

Figure 7.3

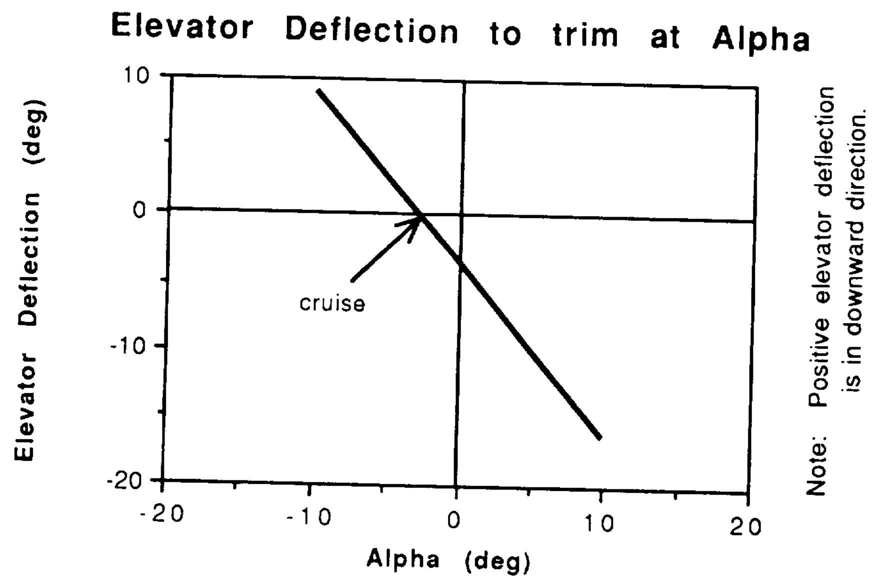


The elevator angle to trim the aircraft may be determined by the following:

$$\delta_{trim}=-(Cmo+Cm_{\alpha}\alpha_{trim})/Cm\delta e$$

where α_{trim} is the angle of attack of the fuselage reference line to the freestream. Refer to Figure 7.4 for the elevator deflection requirement for trim at various α's. At cruise, the Pale Horse must have an upward elevator deflection of 3.6 degrees. Figure 7.4 demonstrates that the Pale Horse will be able to trim at all desired attitudes during flight with a deflection range of +10 and -20 degrees.

Figure 7.4



7.7 Rudder

Two important criteria were reviewed when sizing the rudder. The lateral power produced by rudder deflection must be able to turn the aircraft, (as specified by the mission), without the use of roll control due to ailerons. This defined the smallest rudder area we could tolerate to be one-half the area of the vertical tail. We were also concerned with the structural stability of the fin. To ensure a strong vertical tail attachment to the fuselage, the rudder had to be as small as possible. The control surface is therefore sized at 33.3 square inches, with dimensions of 3 inches by 11 inches high.

The contribution of sideslip to the yaw coefficient was determined when sizing the vertical tail. The rudder component, $Cn\delta r$, was dependent of the rudder effectiveness parameter, and thus, the rudder area. This was calculated by:

$$Cn\delta_r = -\eta V v C l \alpha_V \tau$$

With both $Cn\beta$ and $Cn\delta r$ known, the roll stability could be determined.

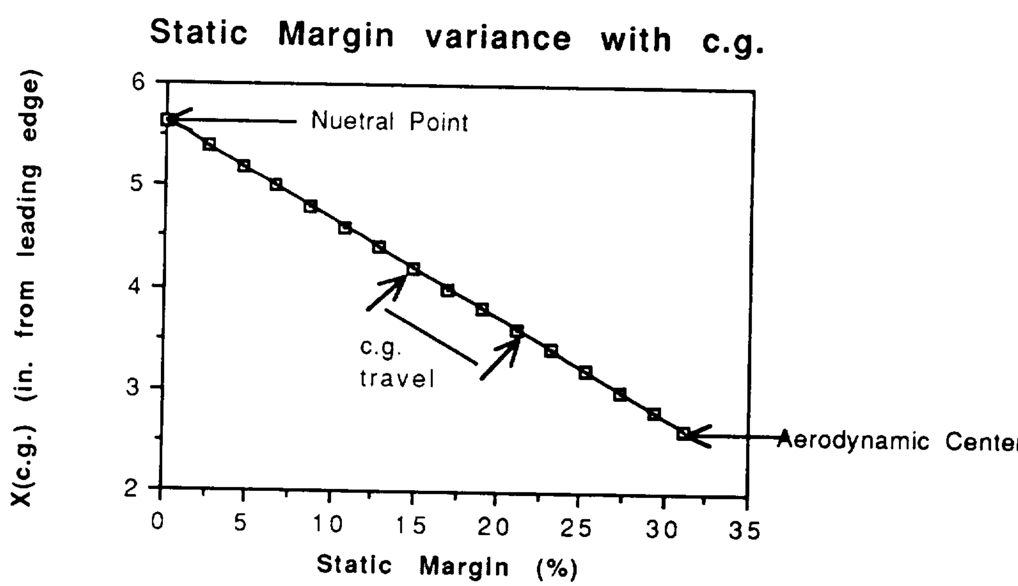
7.8 Static Margin

By calculating the neutral point for the Pale Horse, the aft limit for the center of gravity was determined to be 5.8 inches behind the leading edge of the airfoil. The forward limit was placed at the aerodynamic center of the wing, 2.6 inches from the leading edge, in order to have positive pitching moment from that element. Center of gravity travel was limited even further by specifying a static margin of 20% for a loaded aircraft in cruise. By fixing the static margin at or near this value, the Pale Horse will have desirable handling qualities; the aircraft will respond without over or under-damping at a trimmed maneuver. The stick fixed static margin was calculated by:

$$S.M.=(Xnp-Xcg)/c$$

With the wing chord, neutral point, and static margin fixed, the desired center of gravity was determined to be 3.7 inches behind the leading edge. The travel of the center of gravity due to flight maneuvers and payload will only change the static margin ±2%. Figure 7.5 shows the variance of this value versus the position of the center of gravity.

Figure 7.5



7.9 Summary

The following are the stability and control data for the Pale Horse:

	Wing	Fuselage	Horizontal Tail	Vertical Tail	Aircraft
Chord	10.5		7.5	7.5	
Span	96		22	11	
S	1008		140.25	66.53	
AR	9.14285714		3.45098039	1.81872839	
Vol. Ratio			0.48691291	0.23097551	
Inc. Angle	4.7		2		
Clα	4.13		3.60417445	2.60698596	
Cmα	0.47396667	0.00232	-1.2502511		-0.7739645
Cmo	-0.0417857	0.00006125	0.04201985		0.00029538
Tau			0.57	0.69	
Clδe			0.28584		
Cmδe			-1.0003039		
Cnβ				0.66674179	
Cnδr				-0.4154834	
Delta Rudder				30	
Beta				18.6946484	
Clβ				-0.0369216	
Delta Alpha				3.23451762	

Alpha (craft)	0
Alpha (wing)	4.7
Dihedral	10
((Cl))wing	0.33876091
ε	0.02358804
dε/dα	0.28757333
ε(o)	-1.3280066
Cl (trim)	0.33876091
Alpha (trim)	4.7
Elev. (trim)	-3.6196076

Moment arm =	36.745
X(a.c.)	2.625
X(c.g.)	3.83
X(n.p.)	5.79770631
Static Margin	0.1874006

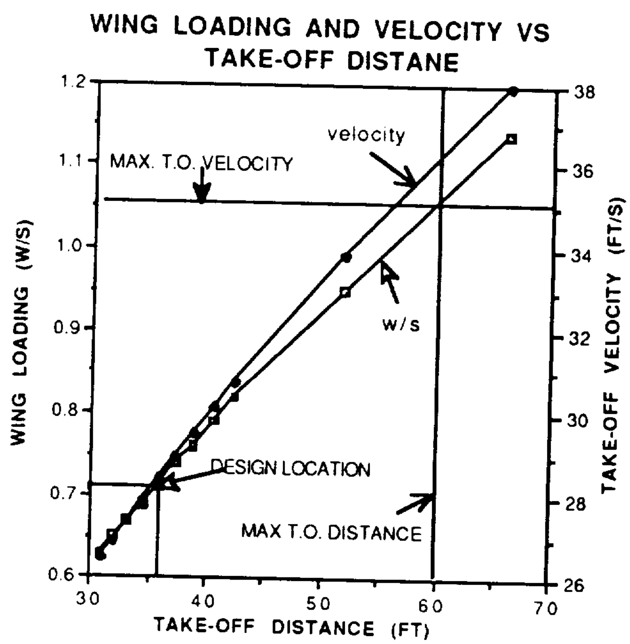
Note: All angles are in degrees and all coefficients are per radian.
X(c.g.) is the origin for the reference system in the average flight condition for the Pale Horse.

Performance

8.1 Take-off and Landing Distance

One of the major requirements for the Pale Horse was the ability to use the available runways in Aeroworld that have a maximum distance of sixty feet. In order to accomplish this goal of having the Pale-Horse take-off in a distance of less than sixty feet, the company decided to employ a propulsion system that included the Tornado10-6 propeller and Astro 15 engine. The Tornado and Astro provide a small necessary take-off distance with ample room to adapt well later date unforseen design changes in the wing loading or take-off velocity(Fig. 8.1.).

Figure 8.1



The propulsion system on take-off provides enough excess runway to compensate for variable last minute maneuvers or pilot error that might be encountered.

The take-off distance was calculated by the two following methods: "Dr. Batill's Take-Off Performance Program", and utilizing equations in <u>Introduction To Flight</u> by Anderson (p.306-311). The performance program, taking into account the Pale Horse's structure and weight, gave a value of 33.2ft. with a take-off thrust of 2.03lb. A rate of climb was found to be 12.8ft/s at a take-off velocity of 28 ft/s.

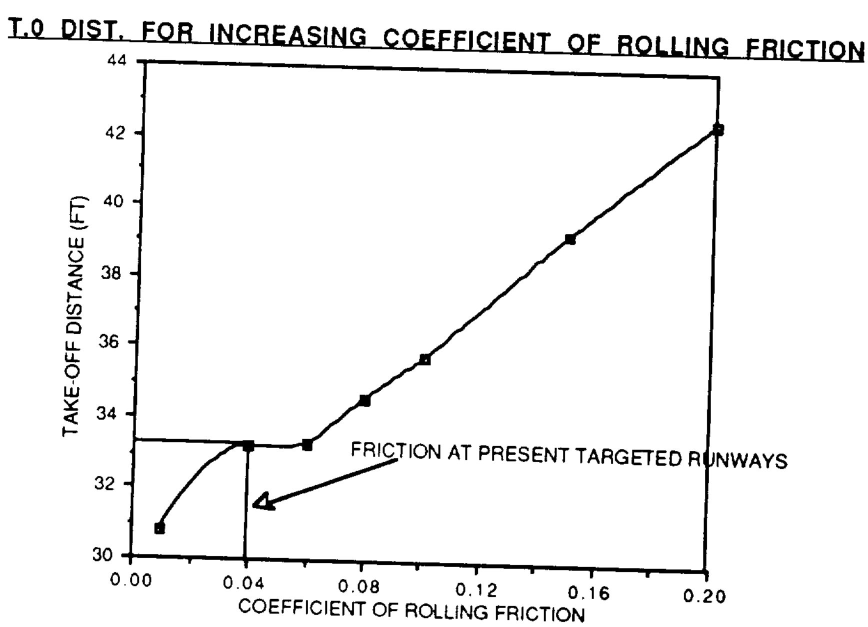
Employing the equations in Introduction To Flight by Anderson, the take off distance was found with the following formula:

$$\text{Take-Off Distance} = \frac{1.44 * W^2}{\rho * g * A * Cl_{max} * (T-(D+\mu*(W-L)))_{.7L}}$$

The drag, weight, and lift parameters were calculated using the Shevell suggestion (Reference 1) that the average forces be set equal to the instantaneous value calculated when the velocity was at seventy percent of take-off speed. Shevell's method gave a take-off distance of 32 feet. This value agrees with the previous determined distance.

The ground coefficient of friction the Pale Horse encounters upon take-off is assumed to be approximately .04. If the coefficient of friction slightly increased, up to about .08 in value, no noticeable difference would occur in the take-off distance for the Pale Horse. If the value for the coefficient of friction became larger than .08, then the distance necessary for take-off would dramatically increase (Fig 8.2).

Figure 8.2



After completing the mission, the Pale Horse will be required to land the craft with the same runway distance constraint that was imposed upon take-off. The landing distance was calculated to be 57.5ft, using the the following equation (Reference 10)

$$\text{Landing Distance} = \frac{1.69 * W^2}{\rho * g * A * Cl_{max} * (D + \mu * (W - L))_{.7VTD}}$$

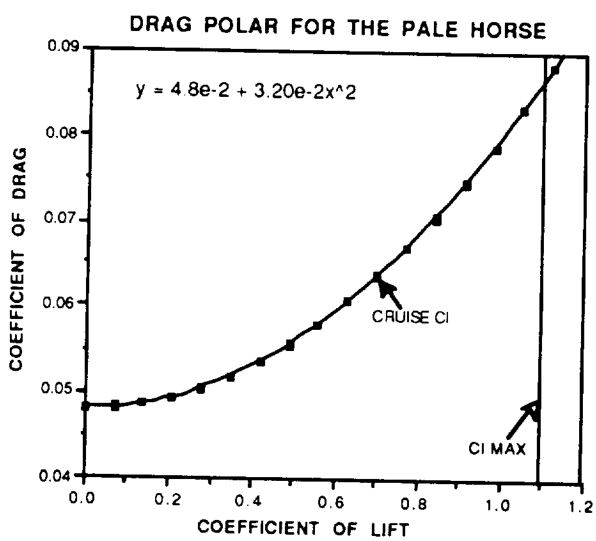
This distance was calculated with the following assumptions:

1) The thrust force control will not be used during landing. The Pale Horse will rely mostly upon the friction coefficient and lack of a forward force to bring the aircraft to a halt.
2) The Shevell suggestion of using the instantaneous values of drag and lift when the velocity is at 70% of take-off was employed to determine the landing distance
3) The coefficient of rolling friction has a value of .04.

The value for the landing distance is near the allowable maximum runway length and only provides a small margin of safety for maneuverability and error. This indicates that some spoilers might be necessary to expedite the reduction of the Pale Horses velocity to decrease the necessary landing distance.

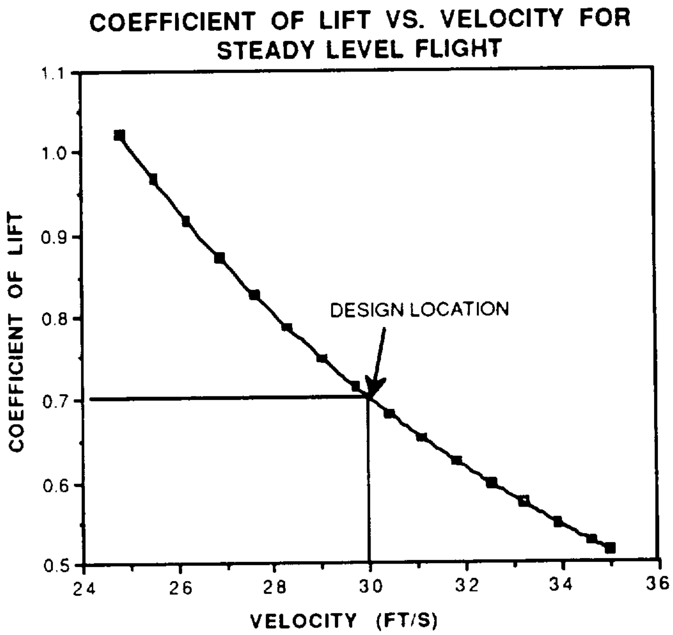
8.2 Lift

The drag polar formula for the Pale Horse is $Cd = .048 + .032 Cl^2$, shown plotted below Figure 8.3



During cruise, the Pale Horse will have a constant velocity of about 30 ft/s. This will give a coefficient of lift of approximately 0.7 (Fig. 8.4). If the velocity increased during flight, the coefficient of lift will stay well below it's maximum value. This will avoid the possibility of the Pale Horse encountering stall during level flight.

Figure 8.4



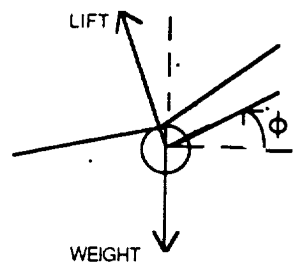
8.3 Turning Radius

The Pale Horse will be required to navigate a turn with a radius of less than sixty feet. It was assumed that the pilot, in order to perform the mission and maintain a constant altitude, keeping the load factor as close to one as possible, will either alter the velocity of the Pale Horse or elevate the aircraft attitude. For the Pale Horse, it is going to be assumed that the plane will try and maintain the cruise velocity of 30ft/s and increase the aircraft attitude. This maneuver can be performed by increasing the lift by employing the elevator control system.

In determining the theoretical turn radius, the following formulas were used:

$$\phi_{max} = \arccos\frac{W}{L} \qquad n = \frac{1}{\cos\phi} \qquad R_{min} = \frac{V^2}{g^*\tan\phi}.$$

These formulas were developed from the following free body diagram:
Figure 8.5



This diagram enables various turning radii, bank angles (φ), and load factors to be determined at the cruise configuration for a range of coefficient of lifts.

Table 8.1

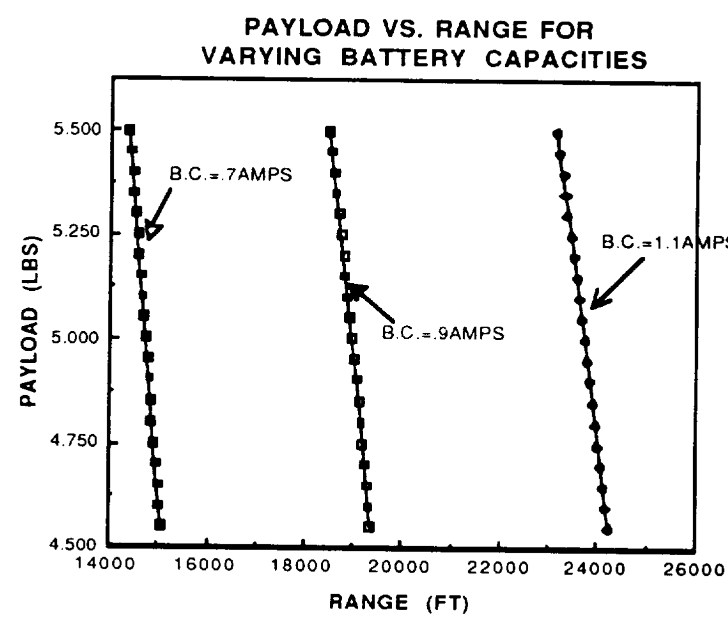
Turning Radius (ft.)	Coefficient of Lift	Bank Angle (deg.)	Load Factor (n)
21.65	1.1	52.24	1.63
30.0	0.92	43.04	1.37
40.0	0.82	34.9	1.21
50.0	0.76	29.1	1.14
60.0	0.74	25.0	1.1

Table 8.1 shows that at the maximum coefficient of lift, 1.1, the Pale Horse can turn with a radius of less than 22ft. However, flying so close to the stall point would be undesirable and very dangerous for our passengers. Therefore, it is desired to perform with a coefficient of lift as close to cruise as possible without exceeding the parameters. With a Cl approximately equal to 0.76, the necessary bank angle will decrease to 29.1 degrees, thus creating a more stable environment for the passengers. The Pale Horse's turn radius will then be 50 feet, leaving an extra 20% room for maneuvering . The load factor is 1.14, well below the maximum load factor value of 2.5. If the velocity is increased, the Pale Horse will still have more than ample room to execute the turn within the given radius parameter.

8.4 Range and Endurance

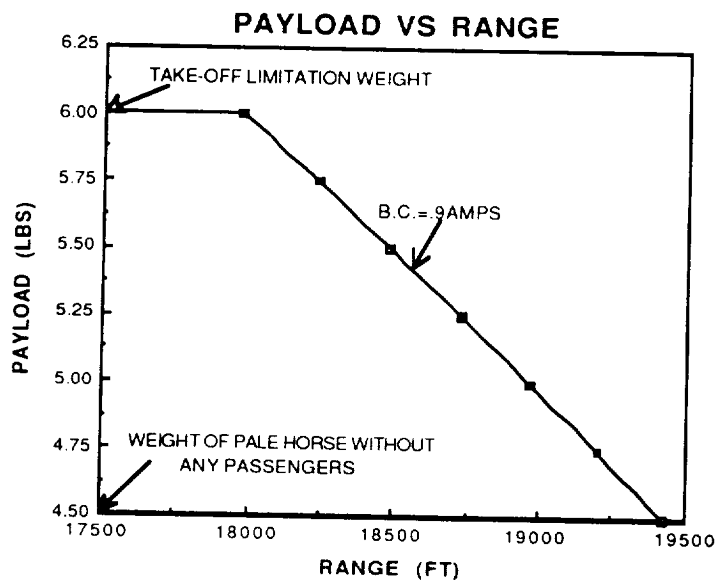
One of the more important design goals in constructing the Pale Horse was to keep the daily maintenance costs to a minimum. This objective was achieved by picking a propulsion system that allows the aircraft to travel great distances without the need of changing the battery. The Pale Horse was designed to perform the scheduled eight missions a day, with an average distance of 2150ft per flight. With a range of 20,000ft and endurance of 10min., the battery will be required to be changed only once per day, cutting the costs in maintenance. The present range was determined with the assumption of having a 1.02 amps battery capacity. The remainder of the battery capacity was assumed to be used during take-off, landing, and any necessary loitering. If this assumption was incorrect and that during this maneuvers a larger percentage of the battery capacity was used, then the available range would decrease. As long as the battery capacity available for steady flight for the eight flights begins at a value greater than 0.8 amps, the Pale Horse will be able to perform its assigned mission. Below 0.8amps, the aircraft will not be able to accomplish all of the designated flights for the day at the present aircraft weight. If the payload weight dramatically decreased for the Pale Horse (the Ping-Pong community all decided to join Weight Watchers) then the range available would slightly increase. Figure 8.6 shows that the available battery capacity of the Pale Horse was a more pertinent paramter in determining the range than the payload weight. With the assumption, based on weight estimates, that the Pale Horse will be at least 4.5lbs without any passengers, it is safe to assume that the payload will not increase the weight by more than one pound, taking into account the average weight of a Ping-Pong person. Examining Figure 8.6 shows that range decreases only marginally.

Figure 8.6



The effects upon the range, with a battery capacity of .9amps, was investigated for the full passenger weight capacity of the plane (Fig. 8.7). The range of the Pale Horse varied by two thousand feet, which is, approximately, one average mission for the Pale Horse.

Figure 8.7



8.5 Performance Data Summary

Table 8.2 Performance Characteristics

Take-Off Distance	33.2ft	Turning Radius	50ft
Time For T.O. Run	2.3s	w/ Bank Angle	~29.1deg.
Take-Off Velocity	28 ft/s	n_{max}	2.5
Take-Off Thrust	2.03lb	Min Glide Angle	2.77 deg
Landing Distance	57.5ft	Rate Of Climb	12.8 ft/s
Max. Velocity	35 ft/s	Cruise Altitude	20 ft.
Cl Max	1.3	Range	20,000 ft
Cl Cruise	.07	Endurance	10.778 min
Cruise Velocity	30 ft/s	Cl cruise	.07

Derivative Aircraft

As the engineers of Grim Reaper Avionics, we have applied many hours to the design of the Pale Horse. As we have done this, ideas for derivatives have sparked our creativity. Small design changes could increase the profit realized by our division of Acme, Inc.

As designed, the Pale Horse is a luxury liner, catering to those who enjoy the comfort of elbow room on their flights. The Pale Horse hods only 30 passengers. By refiguring the interior , room for up to 45 more Aeroworld passengers could be transported per flight. This derivative, the Pale Mule, could provide economy transportation at half the price of the Pale Horse, at the sacrifice of comfort. This derivative entails the fewest changes to our basic design.

For a commuter airplane, the wings could be shortened by not including the portion outboard of the hinge. With a 5 foot wingspan and a shorter fuselage, this design derivative, the Pale Pony, would cater to the shorter routes on Aeroworld, such as F to H. The cost in drag for this airplane would be more than offset by the savings in construction cost, lower engine weight, and maintenance costs. As a support aircraft to the initial Pale Horse fleet, this derivative would be very valuable.

A third derivative is actually illegal at this time, but we hope that a lobby group in Aerocapital could be organized to change the laws in this regard. By increasing the engine size, we would like to skip over supersonic transports and go directly for hypersonic technology. The airframe of this derivative, which we call the Pale Stallion, would obviously have to be strengthened, but we believe that the initial design would not need many changes. The Pale Stallion would be ideally suited to the "prop set" upper class citizens of Aeroworld.

Due to the keel construction of the Pale Horse, it has been suggested that we modify our design towards a more nautical perspective. By replacing the landing gear with pontoons, we would come up with our final derivative: the Pale Seahorse. By using the ocean at ports such as C,E, L, and O, gate sizing and runway considerations would cease to be factors for operating out of those cities. This would by an economical solution to one of out toughest design problems.

Technology Demonstrator

The final step in the production of the Pale Horse was the construction of a prototype to demonstrate the feasibility of the design. The construction process and flight test served to highlight strengths and weaknesses of the initial design.

As anticipated, the hinge was a major problem. Initially it was designed to use an elastic cloth for a joint, allowing tension to keep the wing in position. Spandex was utilized for this purpose, and was found to generate insufficient force to secure the wing. An alternative plan was developed, using the monocote construction material. The top surface of the wing at the joint was covered with a single piece of monocote, while the underside was left separated. This allowed the wing to fold up to a 5 foot span. In flight the bottom is covered with a strong tape in order to keep the wing structurally sound.

The keel of the fuselage has proved to be a strength of the design. It provides a strong platform running the length of the craft to which servos, control rods, batteries, and landing gear can be mounted. The fuselage weighs .824 pounds, which is comparable to the other more conventional designs. Thus we feel that the keel design is a worthwhile innovation.

While monocoting the wing we discovered a major pitfall in the construction of the Pale Horse. As the monocote shrinks, it pulls on the structure. Since it is shrunk unevenly, the wing tends to warp. A severe warp occured in the wing of the Pale Horse, necessitating the repeated heating and bending of the wing to obtain the desired shape.

The Pale Horse was manufactured in a total of 166.5 man-hours, slightly more than the projected figure. On Aeroworld this labor would cost $16,650.00. The cost of materials for the aircraft was $580.00, almost exact to the projected figure. On Aeroworld the final cost for materials would be $232,000.00. Therefore the final cost to produce the prototype was $248,650.00.

Since Grim Reaper Avionics wish to make a 20% profit on the Pale Horse, the final cost of the aircraft is $298,380.00. This cost would decrease in the future due to the aquired expertise learned by producing the prototype.

The final weight of the Pale Horse was 4.8 lb(77 oz), less than the projected figure of 5 lb. Both the fuselage and wing weighted slightly less than their projected weights.

At the time of this writing, the flight test has not yet occured. We feel confident that despite difficulties, the Pale Horse will accomplish the mission for which it was designed.

References

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APPENDIX 1

Output from takeoff   Mon, Apr 8, 1991

```
  INPUT DATA FILE NAME
 tor10-6
 CASE - GROUPA
 WGT =    5.000000
 SREF =    7.000000
 RHO =  2.3779999E-03
 CLTO =  0.7000000
 CDTO =  5.0000001E-02
 CLMAX =    1.100000
 QMAX =   60.00000
 MU =  3.9999999E-02
 DIA =  0.8330000
 BVOLTS =    15.60000
 KT =    1.084000
 KV =  7.9000002E-04
 RARM =  0.1200000
 RBAT =  0.1000000
 FUSAMP =   20.00000
 GEARAT =   2.210000
 DT =  5.0000001E-02
 TMAX =   40.00000
 NJ =           13

 J      CT      CP
   0.0000000       0.1220000       5.0000001E-02
   0.2400000       0.1120000       5.0000001E-02
   0.2900000       0.1040000       5.0000001E-02
   0.3400000       9.7000003E-02   5.0000001E-02
   0.3900000       8.8000000E-02   4.8999999E-02
   0.4400000       7.9999998E-02   4.6999998E-02
   0.4900000       7.1000002E-02   4.5000002E-02
   0.5500000       6.1999999E-02   4.1999999E-02
   0.6000000       5.2000001E-02   3.7999999E-02
   0.6500000       4.1999999E-02   3.3000000E-02
   0.7000000       3.2000002E-02   2.7000001E-02
   0.7500000       2.2000000E-02   2.1000000E-02
    10.00000       0.0000000       -100.0000
 V TAKEOFF =    28.04335
 MAX CURRENT DRAW(amps) =    35.45455
 MAX MOTOR POWER(hp) =  0.3762315
 MAX MOTOR POWER(watts) =    280.5605
 STATIC THRUST (lb)=     2.287986
 STATIC CURRENT DRAW (amps)=     9.951774
 STATIC PROP RPS=     127.9826


 TIME FOR RUN(SEC) =    2.299999
 V AT TO (FT/SEC) =    28.54824
 DISTANCE(FT) =    33.18439
 BATTERY DRAIN(mahs) =    6.366262
 ADVANCE RATIO AT TO =  0.2626656
 THRUST(LB) AT TO =    2.082745
 LIFT(LB) AT TO(BEFORE ROTATION) =    4.569222
 DRAG(LB) AT TO(BEFORE ROTATION) =  0.3263730
 FRICTION(LB) AT TO(BEFORE ROTATION) =  1.7231120E-02
 CURRENT DRAW AT TO (AMPS) =    9.964949

 STOP
```

APPENDIX 2

St	Input	Name	Output	Unit	Comment
		Q	1.0701	psf	dynamic pressure
	.002379	rho		slug/ft3	air density
	30	vel		ft/sec	air speed
		Cd	.06789319		a/c drag coefficient
	.040	Cdo			zero lift drag coefficient
		Cl	.66749436		a/c lift coefficient
	.78	eff			efficiency factor
	9.14	AR			aspect ratio
	1	n			load factor
	5	W		lb	a/c weight
	7	S		ft-ft	wing area
		Preq	20.684689	W	a/c power required - level flight
		ROC	.0006043	ft/s	rate of climb
		Pavail	20.688785	W	power available from propeller
		v	8.7182536	volt	armature voltage
	9.268	vset		volt	battery voltage
	1	Kb			battery constant
		i	5.4974643	amp	motor current draw
		motrpm	10200.706	rpm	motor speed (rpm)
	.12	Ra		ohm	armature resistance
	.00079	Kv		volt/rpm	motor speed constant
		proprps	4615.7041	rpm	propeller speed (rps)
	2.21	gr			gear ratio
		J	.46798632		propeller advance ratio
	.8333	propd		ft	propeller diameter
		eta	.76462486		propeller efficiency
	1.084	Kt		in-oz/amp	motor torque constant
	.95	greff			gear efficiency
		fltime	667.94432	sec	flight time
	1.02	batcap		amp-hr	battery capacity
		range	20038.329	ft	range
		CT	.07496246		
		CP	.04588055		